RASCAL

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Responsive Access, Small Cargo, Affordable Launch

Introduction Briefing
Aug, 2001

Objective:	***Responsive, Routine & Small-Scale access to space***
Approach:	***Blend of Reusable & Expendable vehicles***
	Aircraft reusable first-stage capable of Exo-Atmospheric Flight
	Low-cost expendable upper stages
Goals:	***50 kg to LEO Anytime, Any Inclination.***
	High Flight Rate, on-time performance, low cost

Space Access for Exploring Military Space CONOPS and Technology

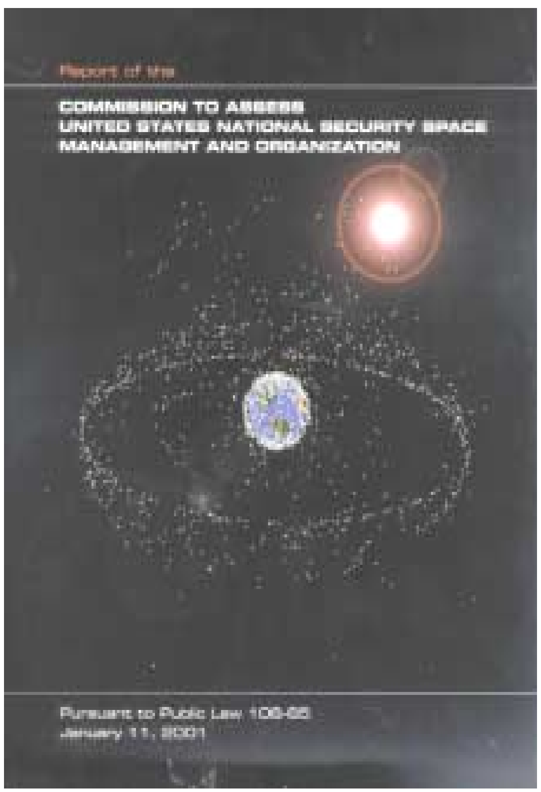
DARPA

MOTIVATION

TTO
Tactical Technology Office

"United States deterrence and defense capabilities depend critically on assured and timely access to space. The U.S. Should continue to pursue revolutionary reusable launch vehicle technologies and systems even as the U.S. moves to the next generation of expendable launch vehicles…. One key objective of these technological advances must be to reduce substantially the cost of placing objects and capabilities in orbit…."

Secretary of Defense Donald H. Rumsfeld



***Report of the Commission to Assess United States National Security Space Management and Organization*, January 11, 2001.**

Payoffs: Assured and timely access to space for U.S. defense

Acts as an enabler for new missions:

–New military space missions, Orbital Express, BMDO targets

–Space Test Program (STP) payloads, Space hardware qualification

PROGRAM DESCRIPTION

Objective: **Develop a Responsive, Routine, access to space for Small Payloads**

Approach: **Blend of Reusable & expendable vehicles**

- **Reusable aircraft first-stage capable of Exo-Atmospheric flight**
- **Low-cost expendable upper stages**

Goals: **50 kg (110 lbs) to LEO, anytime, any inclination**
high flight rate, on-time performance, Low Cost

Payoffs: **Assured and timely access to space for U.S. defense**

Acts as an enabler for new missions:

–New military space missions
–BMDO targets
–Space Test Program (STP) payloads
–Space hardware qualification
–Orbital Express type missions

LAUNCH ELEMENTS

Notional Vehicle Design

Reusable 1st stage vehicle

- Free from launch pads & ranges
- Able to access all inclinations
- Resilient against launch denial

Payload Satellite

- Rapid delivery and operation
- Lower acoustic loads during ascent

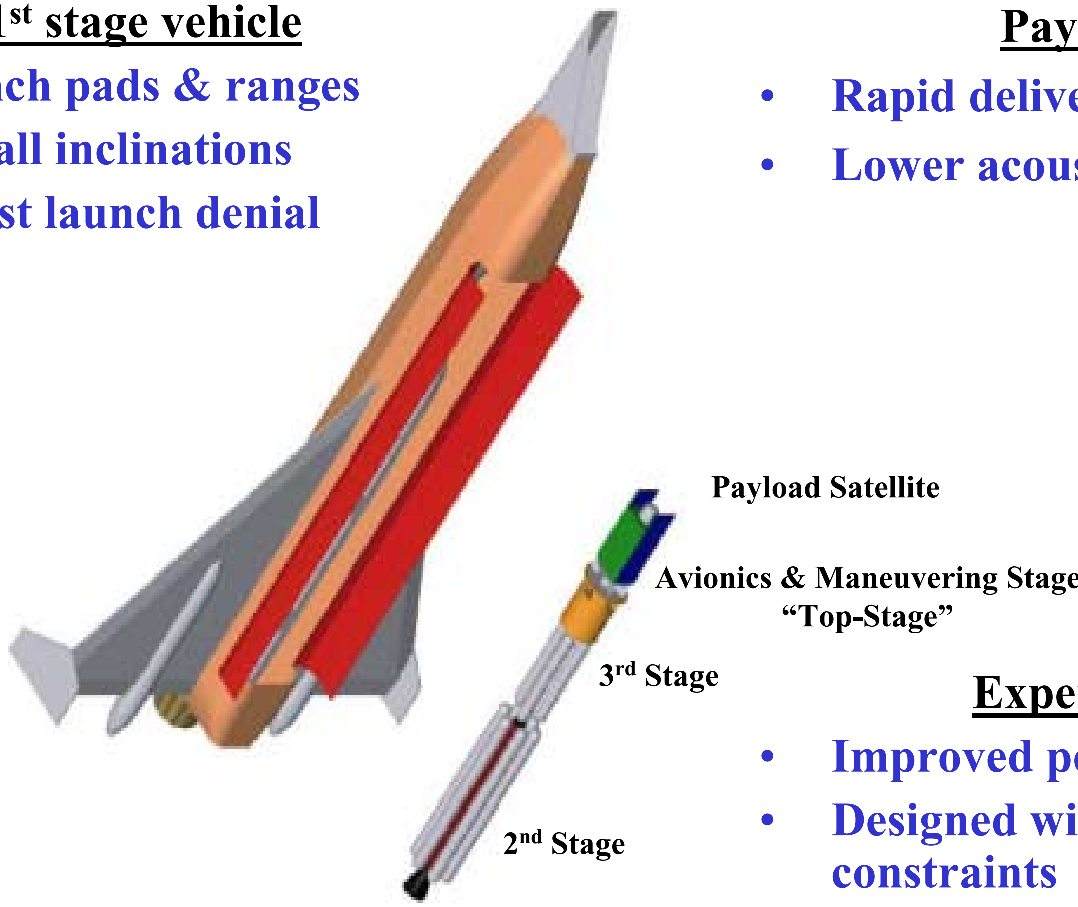
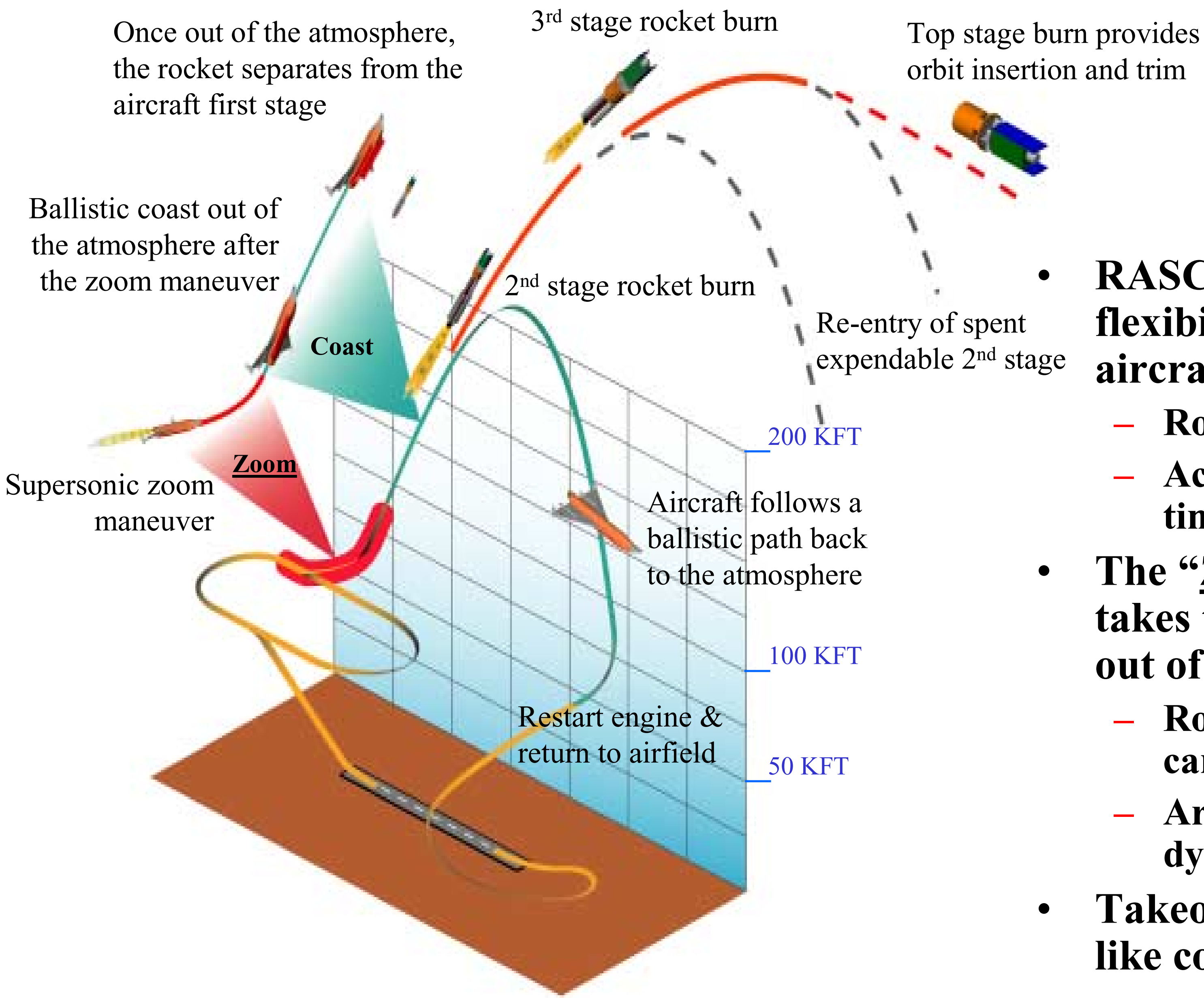


Illustration of the 1st Staging Event

Expendable Rocket

- Improved performance at lower cost
- Designed without aerodynamic constraints
- No payload fairing required

CONOPS



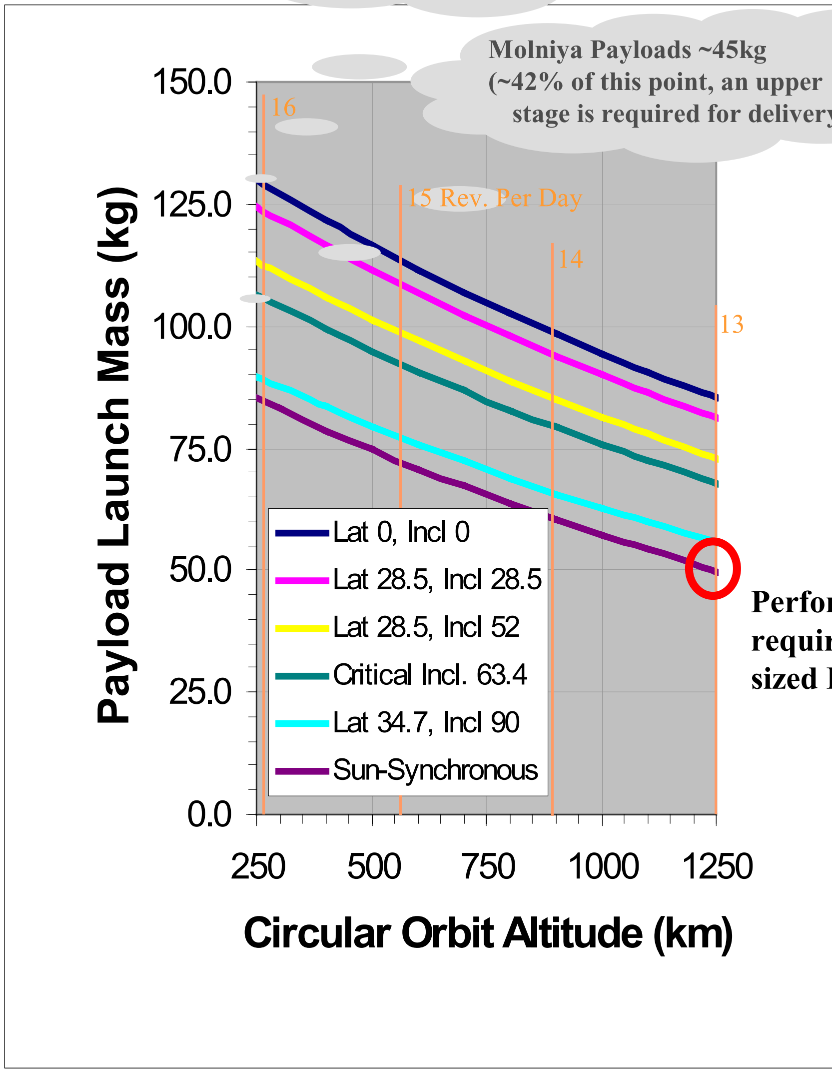
- **RASCAL CONOPS has the flexibility common to aircraft**
  - **Routine, airfield based ops**
  - **Access to any orbit, any time**
- **The "Zoom" maneuver takes the aircraft and rocket out of the atmosphere**
  - **Rocket & payload are carried internal to aircraft**
  - **Are never subjected to high dynamic pressure loads**
- **Takeoff and landing are just like conventional jet aircraft**

ORBITAL & BALLISTIC PERFORMANCE

Orbital Delivery Potential

GEO Payloads ~33kg (~25% of this point, an upper stage is required for delivery)

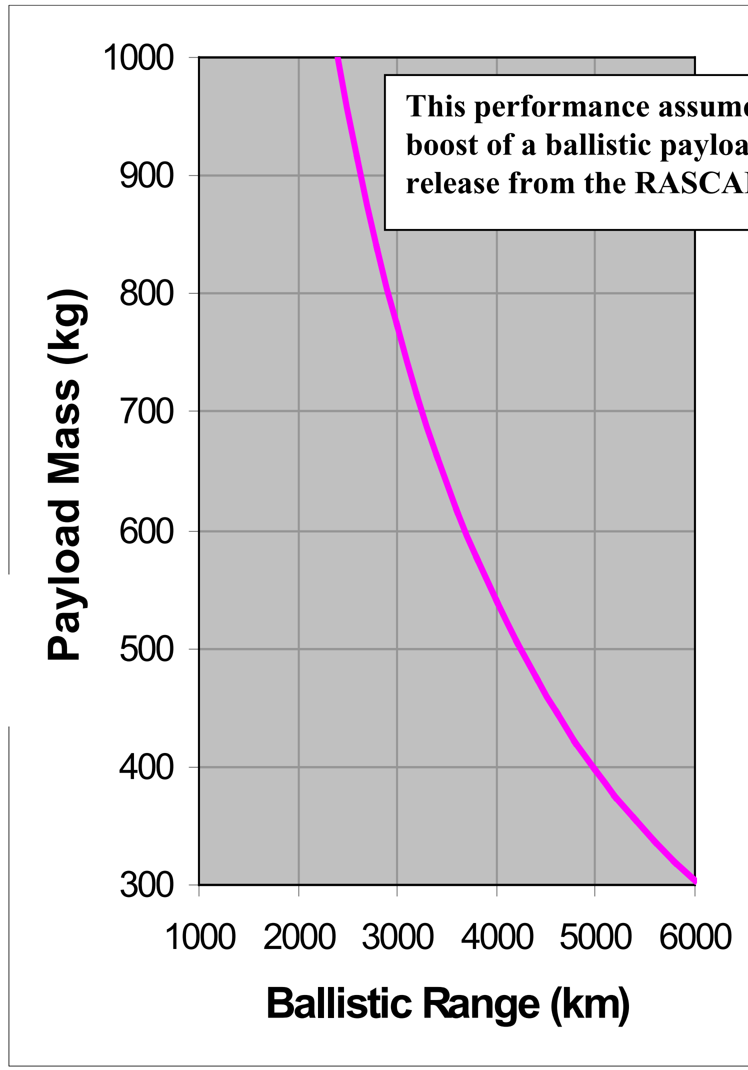
Molniya Payloads ~45kg (~42% of this point, an upper stage is required for delivery)



Performance requirement that sized RASCAL

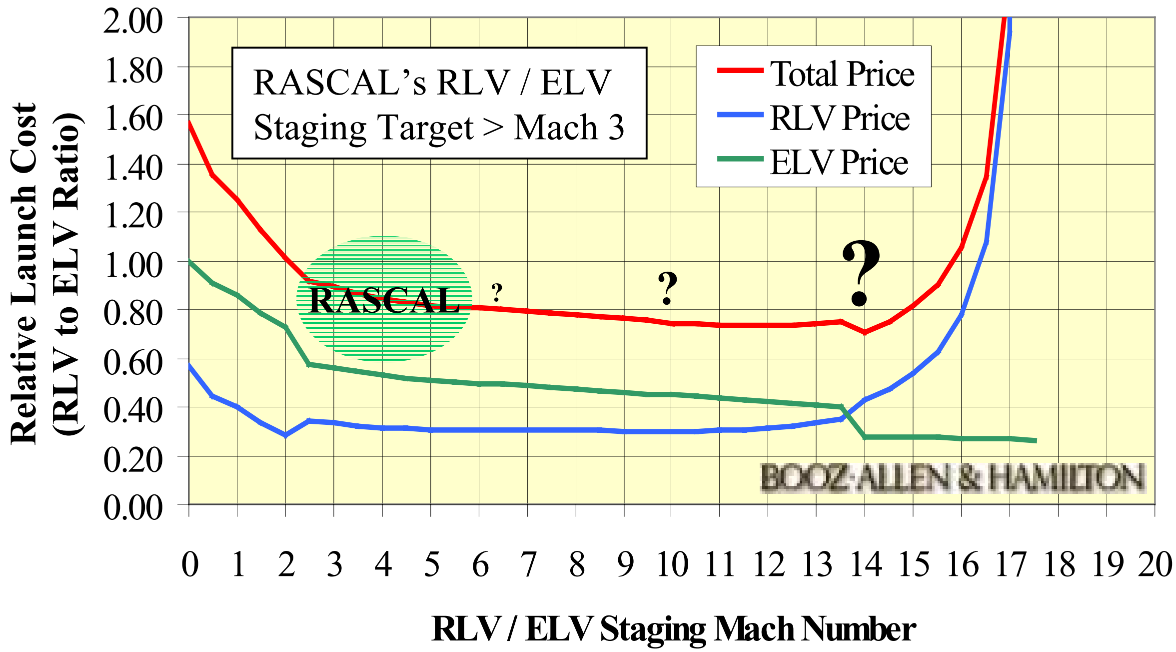
Ballistic Delivery Potential

This performance assumes a one-stage boost of a ballistic payload after release from the RASCAL aircraft

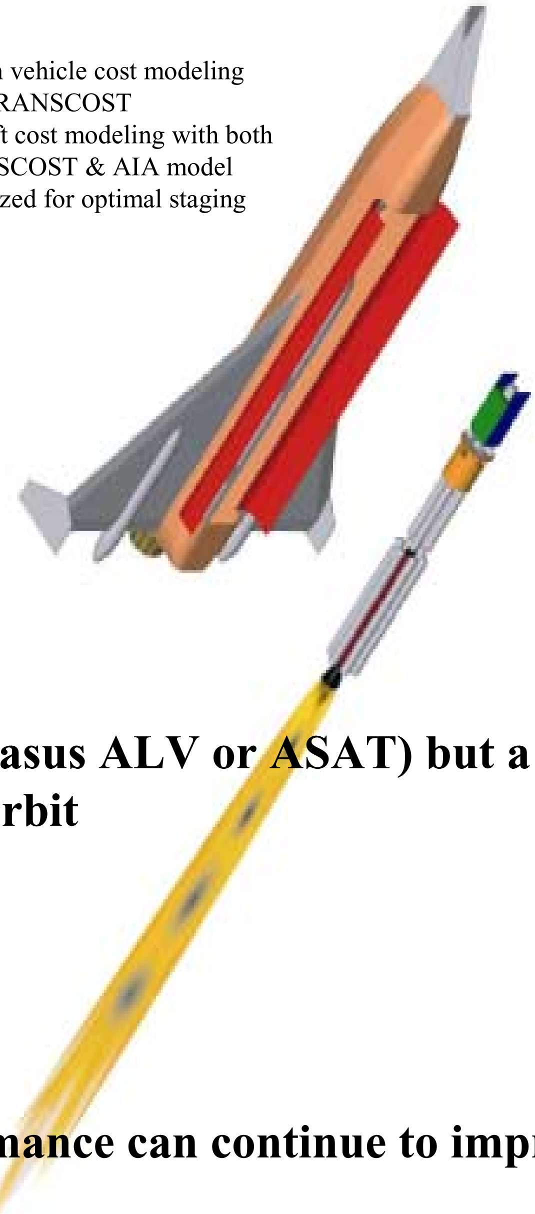


RASCAL COST PAYOFF

Launch Cost as a function of Staging Mach Number



- Launch vehicle cost modeling with TRANSCOST
- Aircraft cost modeling with both TRANSCOST & AIA model
- ELV sized for optimal staging



- **The aircraft is not just a "Launch Platform" (like Pegasus ALV or ASAT) but a significant contributor to the acceleration to achieve orbit**
- **The Zoom maneuver <u>reduces throw away mass</u>**
  - **Improves overall system performance**
  - **Reduces recurring vehicle costs**
- **Exo-atmospheric staging <u>reduces launch risk</u>**
- **As propulsion technology advances, RASCAL performance can continue to improve with little or no modification to the basic approach**

CHALLENGES / APPROACHES

Exo-Atmospheric High-Speed RLV

Challenges

- **Acceleration to an Exo-Atmospheric Sub-Orbital Trajectory**

  Issue: Availability of highly reusable propulsion to high Mach number and high altitudes

  Goal: >Mach 3, >100 kft altitude

- **RLV / ELV Launch Separation**

  Issue: Safe separation of the RLV from the ELV before ELV ignition

  Goal: Operationally routine and safe RLV / ELV Separation

Technical Approaches

- **Acceleration to an Exo-Atmospheric Sub-Orbital Trajectory**
  - Utilize exist, or near-term, reusable engines suitable for this boost function
    - Adapt existing military jet engines to this exo-atmospheric application with Mass Injection Pre-Cooling (MIPC)
    - Existing reusable rocket engines suitable for aircraft installation
    - The integrator, with DARPA, will choose the engine approach after the system design phase
- **RLV / ELV Launch Separation**
  - ELV will be designed to hold attitude upon separation, RLV will have the ability to rapidly translate during exo-atmospheric flight

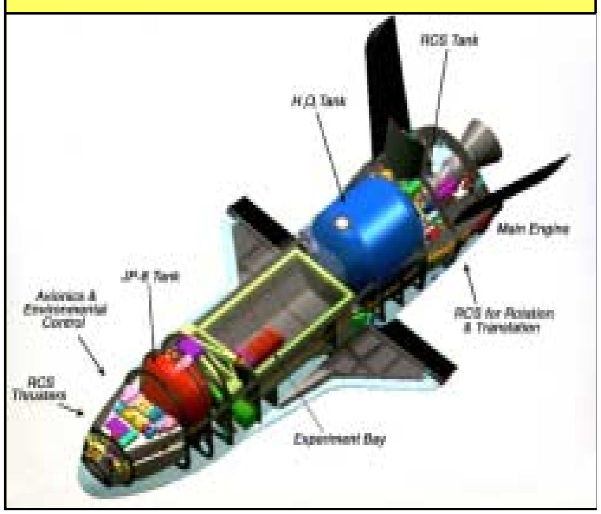
EXO-ATMOSPHERIC

HIGH-SPEED RLV'S

The X-15 program developed most of the required technology for exo-atmospheric flight

First the NF-104, and then the Space Shuttle, have provided almost 30 years of operational experience with exo-atmospheric flight

NASA's X-37 is a current example of an exo-atmospheric vehicle with all the sub-systems required by RASCAL



- **Historical experience with exo-atmospheric aircraft is good**
- **Current technology sub-systems are available**
- **The RASCAL challenges will be:**
  - Reusability
  - RLV / ELV Release & Separation (staging)
  - Integration

CHALLENGES / APPROACHES

Low Cost ELV

Challenges

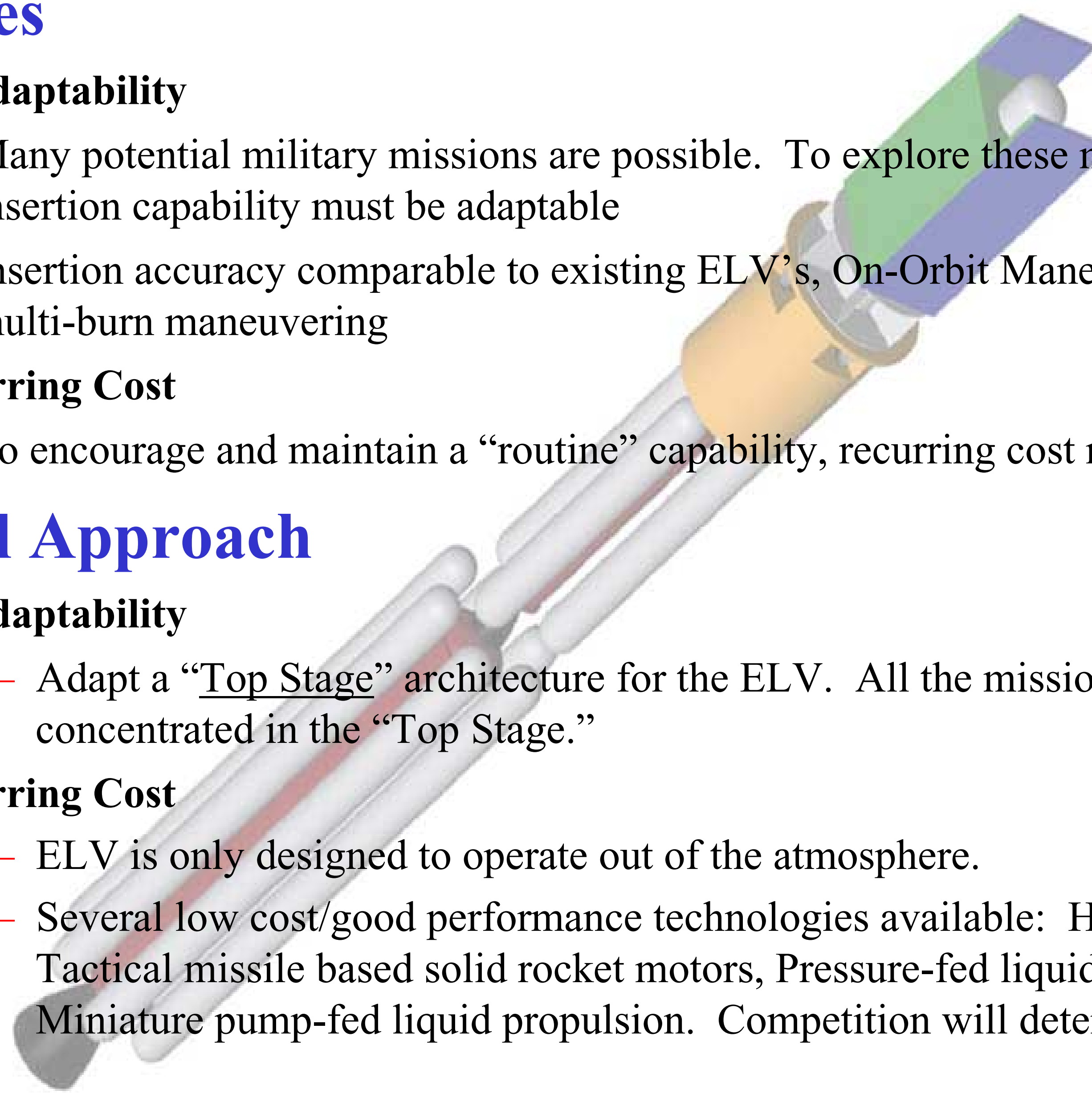
- **Mission Adaptability**

  Issue: Many potential military missions are possible. To explore these missions, the orbit insertion capability must be adaptable

  Goal: Insertion accuracy comparable to existing ELV's, On-Orbit Maneuvering > 300 mps, multi-burn maneuvering

- **Low Recurring Cost**

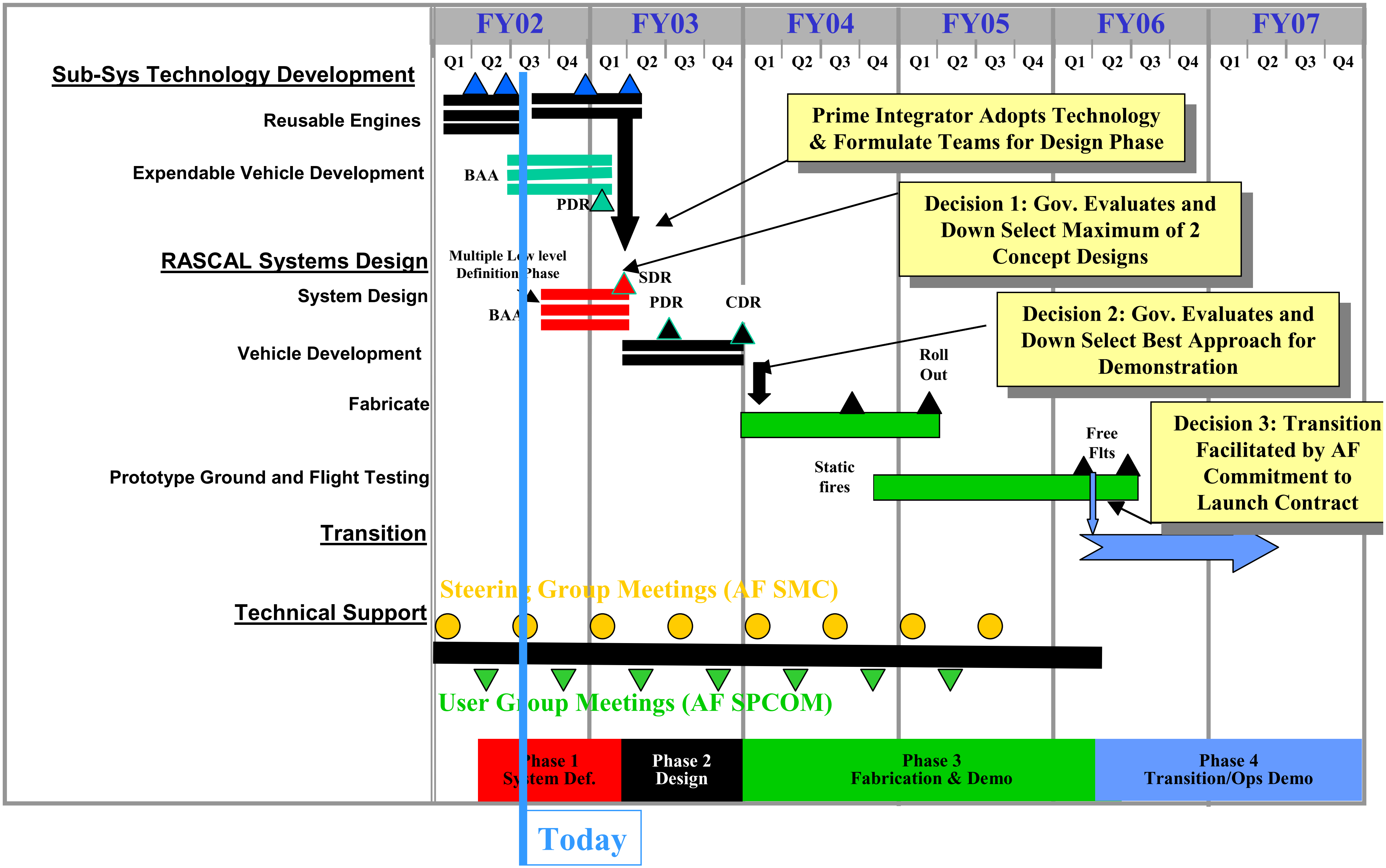
  Issue: To encourage and maintain a "routine" capability, recurring cost must be low



Technical Approach

- **Mission Adaptability**
  - Adapt a "Top Stage" architecture for the ELV. All the mission specific features are concentrated in the "Top Stage."
- **Low Recurring Cost**
  - ELV is only designed to operate out of the atmosphere.
  - Several low cost/good performance technologies available: Hybrid rocket motors, Tactical missile based solid rocket motors, Pressure-fed liquid propulsion, and Miniature pump-fed liquid propulsion. Competition will determine the "Winner."

RASCAL PROGRAM PLAN

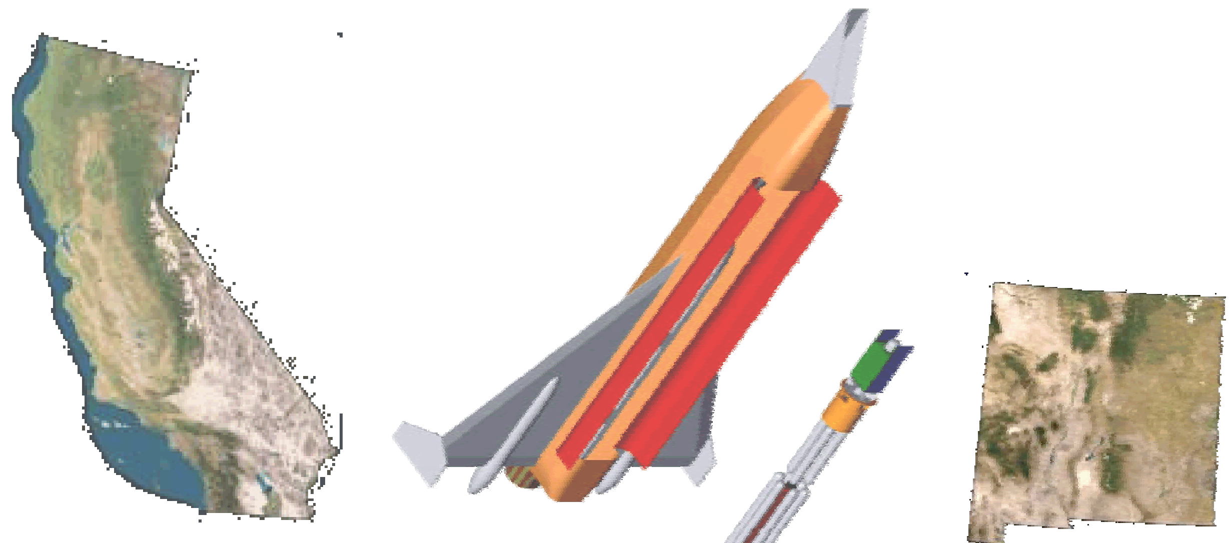


RASCAL PHASE I PERFORMERS

- **Coleman Research Corp – Vela Tech, Pan Aero, BAE Sys, XCOR, HMX, Spath, CCT, CSA, APRI**
- **Delta Velocity – A²I² , ATK, APRI, NASA, Edwards AFB, CSA Engineering, Athena Technologies**
- **Northrop/Grumman – Orbital Sciences Corp, Pratt & Whitney, Scaled Composites, Spath, NASA, APRI**
- **Pioneer/HMX – Scaled Composite, Rocket Prop Eng, SLC, Microcosm, Universal Space Lines, Athena Tech, Orbital Technology, Aurora**
- **Space Access – Honeywell, APRI, Spath, EPRI, ATK, Micrcosm, IRA**
- **Space Launch Corp – Scaled Composite, USL, Aprize Satellite, Templar Corp., BAE Sys, Pratt & Whitney**

UNIVERSITY OF CALIFORNIA SPACE PORTAL

University of California can operate a RASCAL system to nurture space research and development



- **The Opportunity:**
  - **Promote and support high quality, early-stage research**
  - **Speed the utilization of research discoveries for public benefit, by facilitating technology transfer**
  - **Support the training environment that prepares California's future workforce and industry leaders**
  - **Advance understanding of the role of science and technology in California's increasing knowledge-based economy**

SUMMARY

- **Potential for revolution in rapid access to space**
  - **Reusability supported by high flight rate (small payloads)**
  - **Exo-atmospheric staging allows evolution to higher performance**
- **Supports space operations**
  - **Directly addressed an identified AFSPC mission need**
  - **Latent need already exists**
- **Manageable technology challenges**
  - **Extension of aircraft airframe & propulsion technologies**

- **Acquisition plan has decision points & exams**

- **Transition plan follows successful examples**

Rapid Access, Small Cargo, Affordable Launch (RASCAL)

Back - Ups

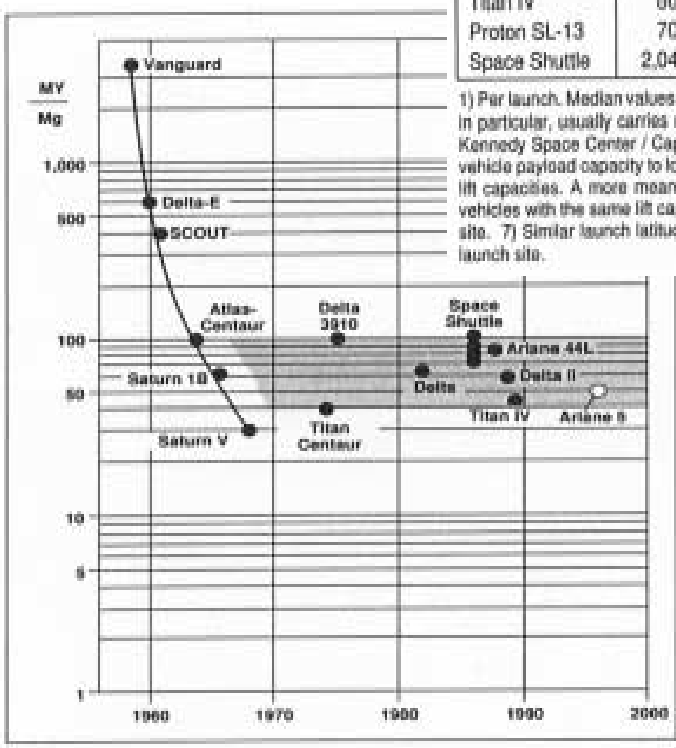
LAUNCH COST TRENDS

A Survey of Current Launch Cost

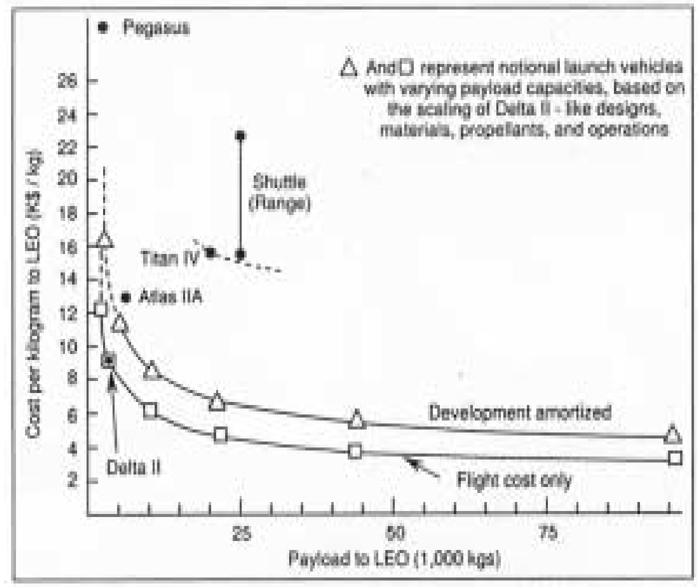
Vehicle	Liftoff Mass (kg)	Cost Range ($M)[1]	Payload Capacity to LEO ($kg)[2]	Payload Launch Efficiency ($ per kg)[3]
Pegasus	19,050	$13M–$15M	454	$30,800
LLV-1	66,225	$15M–$17M	794	$20,200
Taurus	81,650	$18M–$20M	1,451	$13,100
Titan II	155,000	$35M–$40M	1,905[4]	$19,700
Vostok SL-3	290,000	$20M–$30M	4,717[5]	$5,300
Delta II 7920	218,300	$45M–$50M	5,035	$9,400
Atlas IIA	187,700	$80M–$90M	6,760	$12,600
Ariane-44LP	420,000	$90M–$100M	8,300[6]	$11,400
Long March 2E	464,000	$40M–$50M	9,210[7]	$4,900
H-2	264,000	$150M–$200M	10,433[8]	$16,800
Titan IV	862,000	$230M–$325M	17,700	$15,700
Proton SL-13	703,000	$35M–$70M	20,000[5]	$2,600
Space Shuttle	2,040,000	$350M–$547M	23,500	$19,100

1) Per launch. Median values used for calculations. 2) Assumes the vehicle's full payload capacity. The Shuttle, in particular, usually carries much less than its full capacity. Capacities listed are for a due east launch from Kennedy Space Center / Cape Canaveral Air Station (latitude 28.5 deg) except as noted. 3) Cost divided by vehicle payload capacity to low-Earth orbit. Note these launch efficiencies are for vehicles with a wide range of lift capacities. A more meaningful use of payload launch efficiencies would be to compare different launch vehicles with the same lift capacity. 4) Polar orbit. 5) 51.6 deg latitude launch site. 6) 5.2 deg latitude launch site. 7) Similar launch latitude to Kennedy Space Center / Cape Canaveral Air Station. 8) 30.0 deg latitude launch site.

Historical Trend in Launch Costs



The Trend in Launch Cost Versus Scale



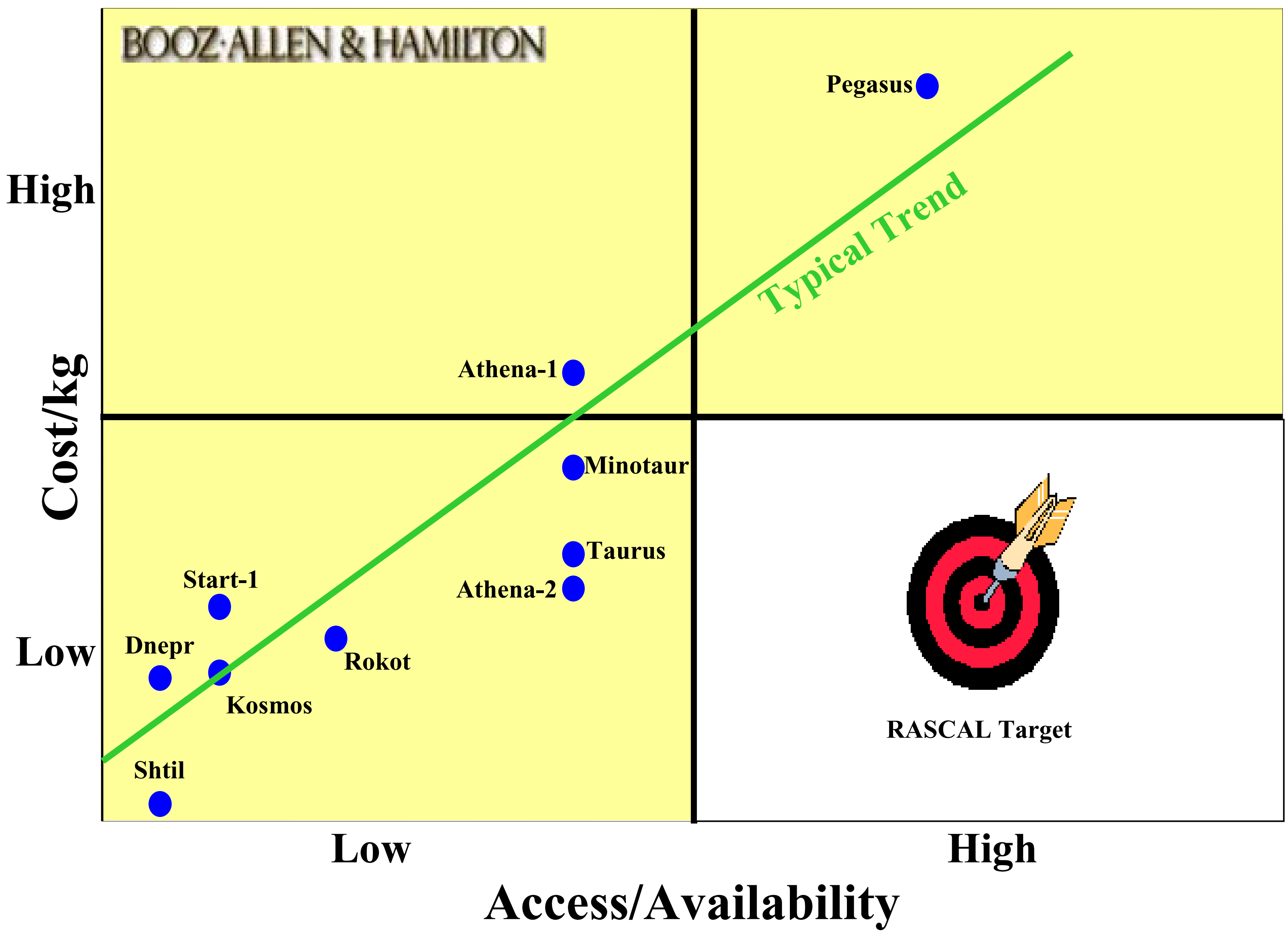
- **Progress in reducing launch costs has stagnated at $5K to $10K per kilogram**
- **Cost of dedicated launch of small payloads is 5x to 10x that of larger payloads**

*** Data from "Reducing Space Mission Cost," Edited by Wertz and Larson**

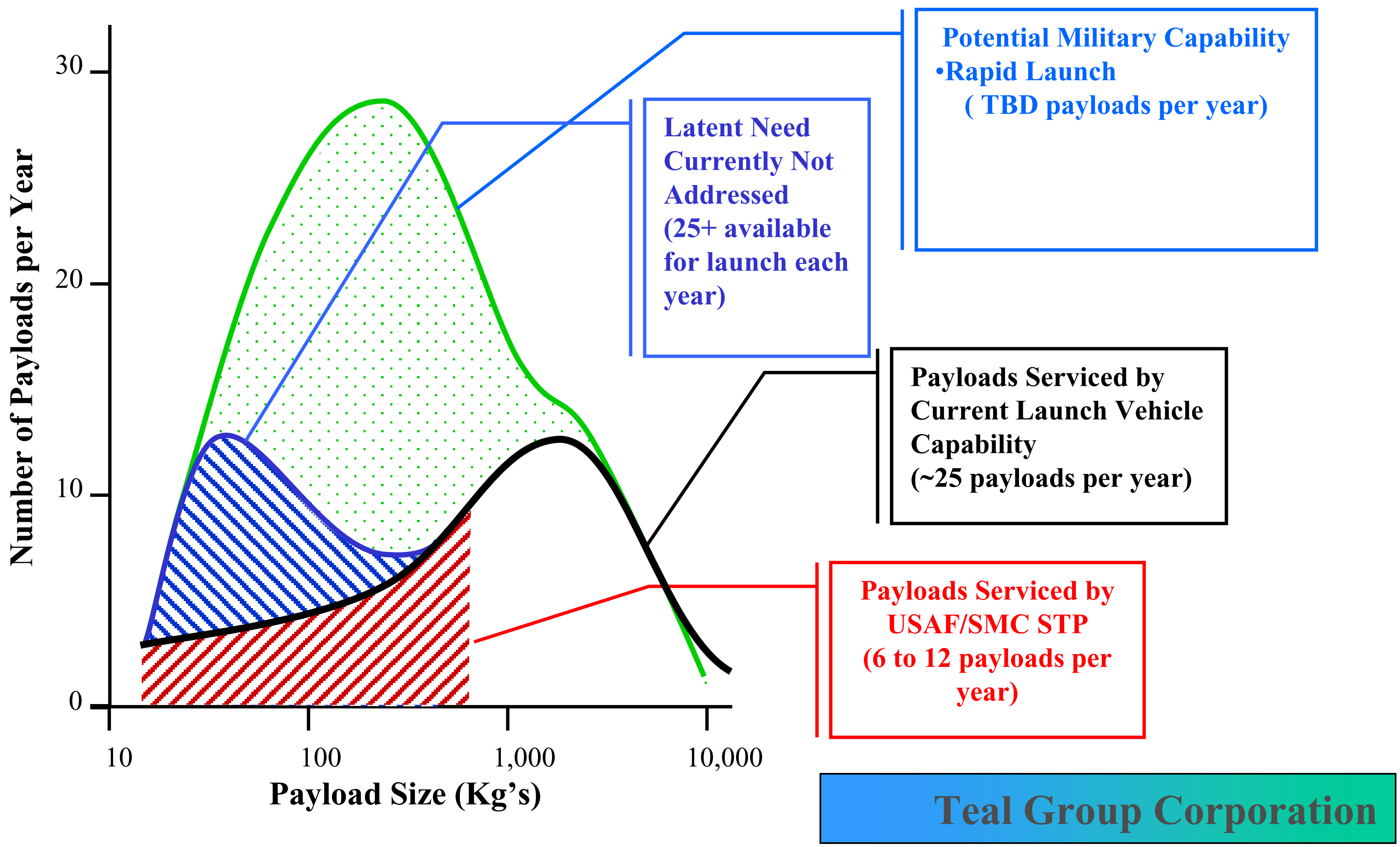
"R" IN RASCAL = RESPONSIVE, ROUTINE & RELIABLE

- **Responsive**
  - Freedom from launch pads
  - Freedom from ranges
  - Integration of stages like hanging tactical ordnance
- **Routine**
  - Cost ≈ Tomahawk
  - Aircraft-like ops
  - Short lead time to integrate
- **Reliable**
  - Benign vibration & acoustic environment enhances reliability of payloads
  - Fewer components (e.g. no fairing, no thrust vectoring, no aerodynamic surfaces) enhances upper stage reliability
  - Ultimate high launch rates feed into manufacturing/QA, leading to inherent high reliability (1st stage ≈ commercial aircraft, 2nd stage ≈ tactical missile)

REVOLUTIONIZING SMALL LAUNCHER ACCESS AND COST



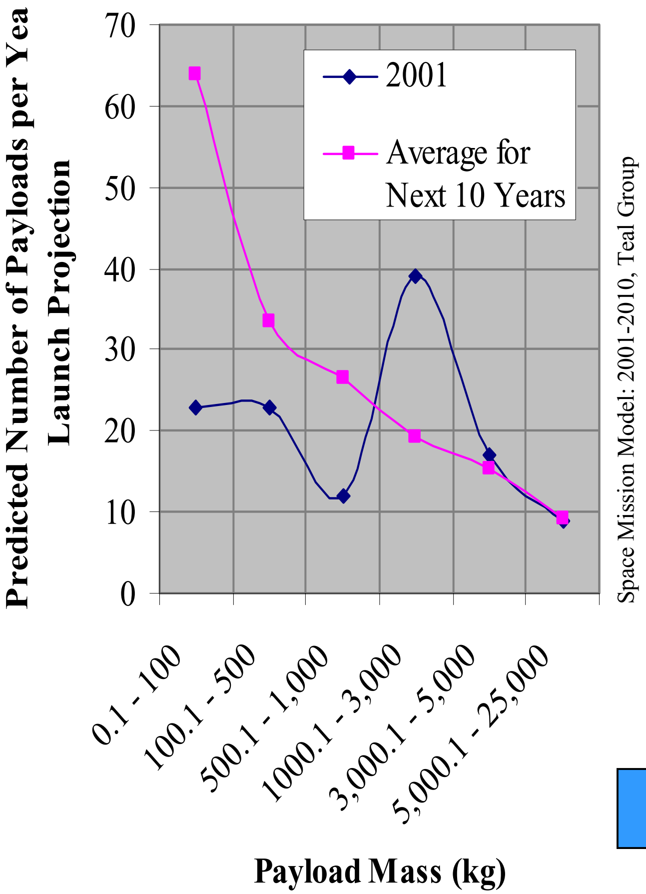
Distribution of DoD Payloads



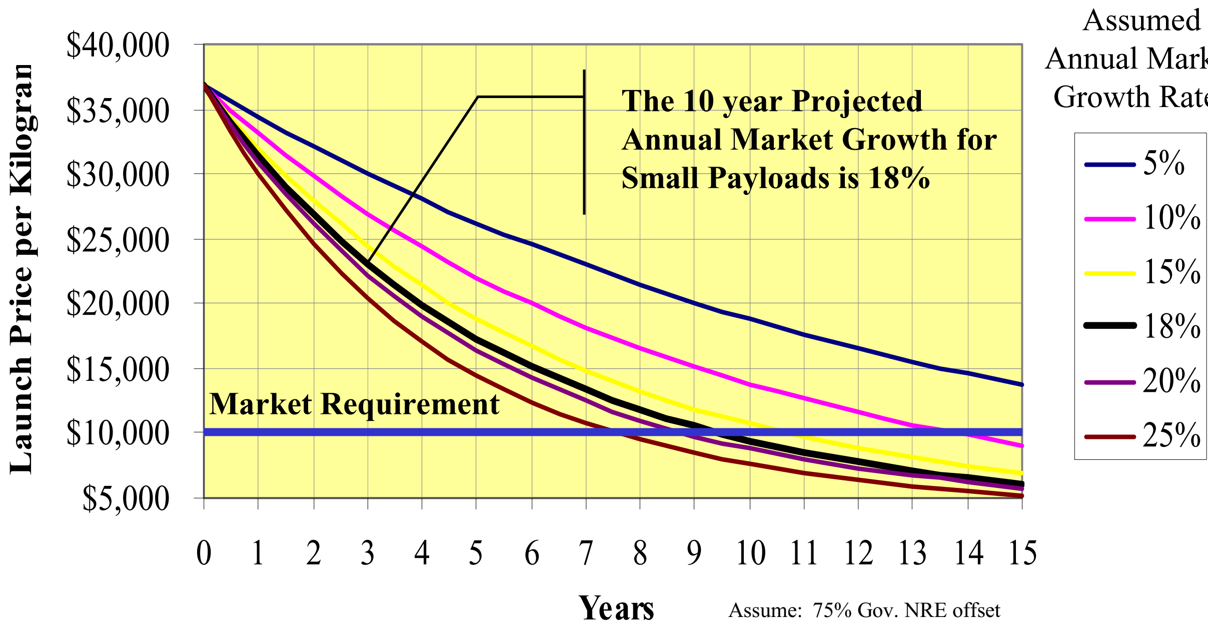
Insufficient small spacecraft launch capability exists today, inhibiting DOD's ability to utilize space effectively, efficiently and rapidly.

SPACE LAUNCH INDUSTRY

The World Space Payload Market is Shifting to Smaller Payload Sizes



The Price Performance of the RASCAL Launch Approach will out perform Market Requirement in about 10 years



Assume: 75% Gov. NRE offset
Required IRR of 20% over 5 years
Development Cost $120 M
Recurring HW Cost of $250K per flight
Range Ops cost of $100K per flight
Initial market of 20 flights per year
Performance annual improvement of 3%

Teal Group Corporation

RASCAL has the characteristics of being a disruptive technology to Today's ELV space launch approach

SYSTEMS FEATURES VS. APPLICATIONS

Applications | **Mission Features** | **Potential Approaches**

Mission Features	Commercial	NASA/Government	Space Qualification	Space Test Program	"Orbital Express"	National Assets	Force Projection	Force Enhancement	Space Support	Ground launch ELV	Small ELV	Air Launch, Subsonic	Air Launch, Supersonic (RASCAL)
Rapid Access	★				★	★	★	★	★			★	★
Flexible Operations (Orbit Inclination)	★	★		★	★	★	★	★	★			★	★
Dedicated Launch of Small Payloads	★	★	★	★	★	★		★	★		★	★	★
Affordable	★	★	★	★	★								★

MATCH CAPABILITY WITH MISSIONS

DARPA

TTO Tactical Technology Office

Orbit Types

- KSC Due East 28.5º Incl., LEO
- Polar
- Sun Synchronous
- Critical Inclination
- Equatorial
- Other
- Ballistic

Orbital Altitudes / Shape

- Cir. 13 - 15 Rev/Day, other
- Cir. 13 - 15 Rev/Day, other
- Cir. 13 - 15 Rev/Day, other
- Cir. 13 - 15 Rev/Day, Molynia, other
- LEO, GEO
- Other
- Intercontinental, Theater

A minimum payload of 50 kg to any Low Earth Orbit (LEO)*, ** provides a board capability to many missions and applications

Missions & Applications

- Space Support
- Force Enhancement
- Force Projection
- National Assets
- "Orbital Express" Infrastructure
- Space Test Program
- Space Qualification
- NASA / Governmental
- Commercial

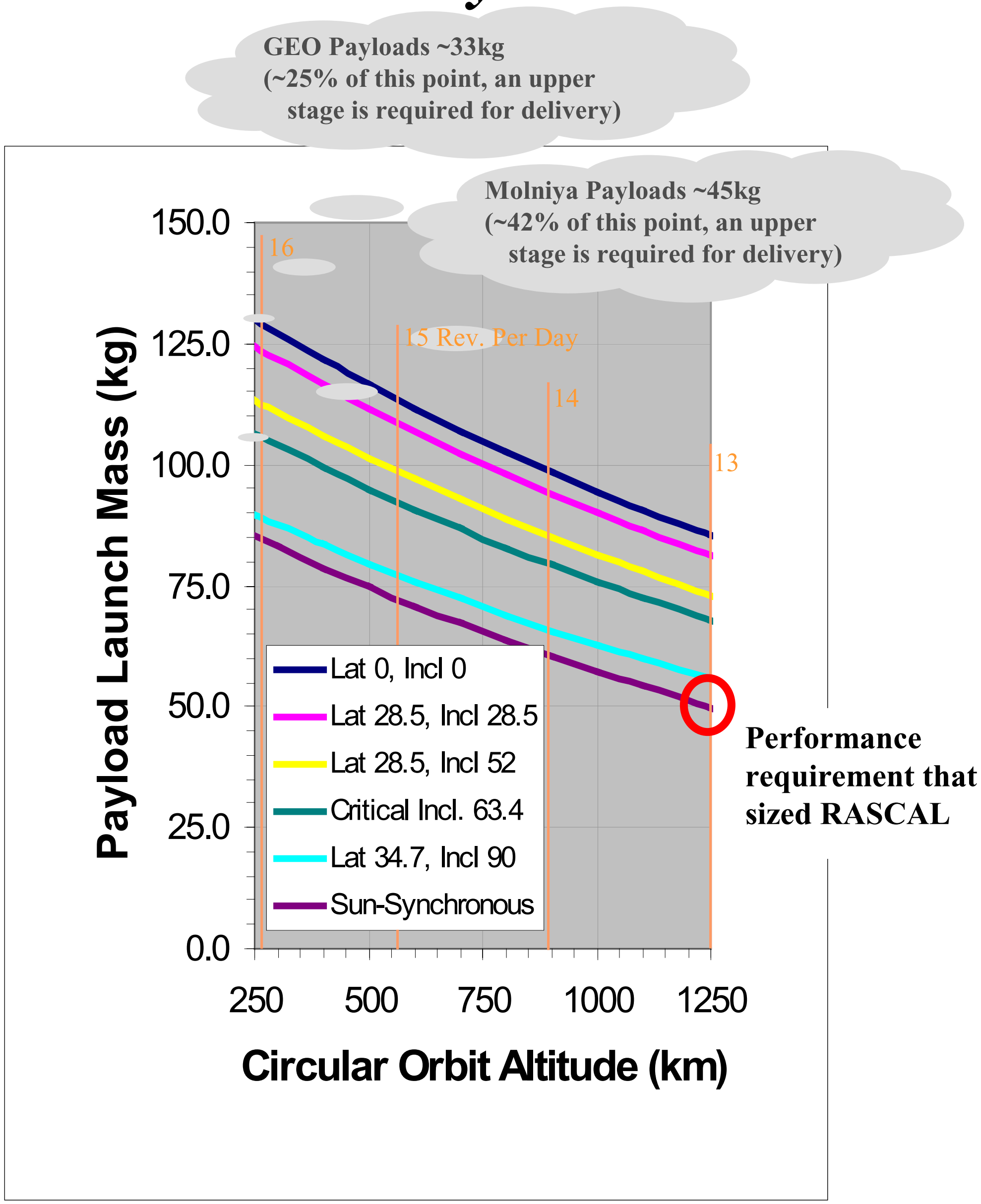
- Compatible
- TBD
- Reduced Compatibility
- N/A

* LEO is defined as any orbit with a period greater then 13 rev/day and an inclination between 0° and a Sun Synchronous inclination.

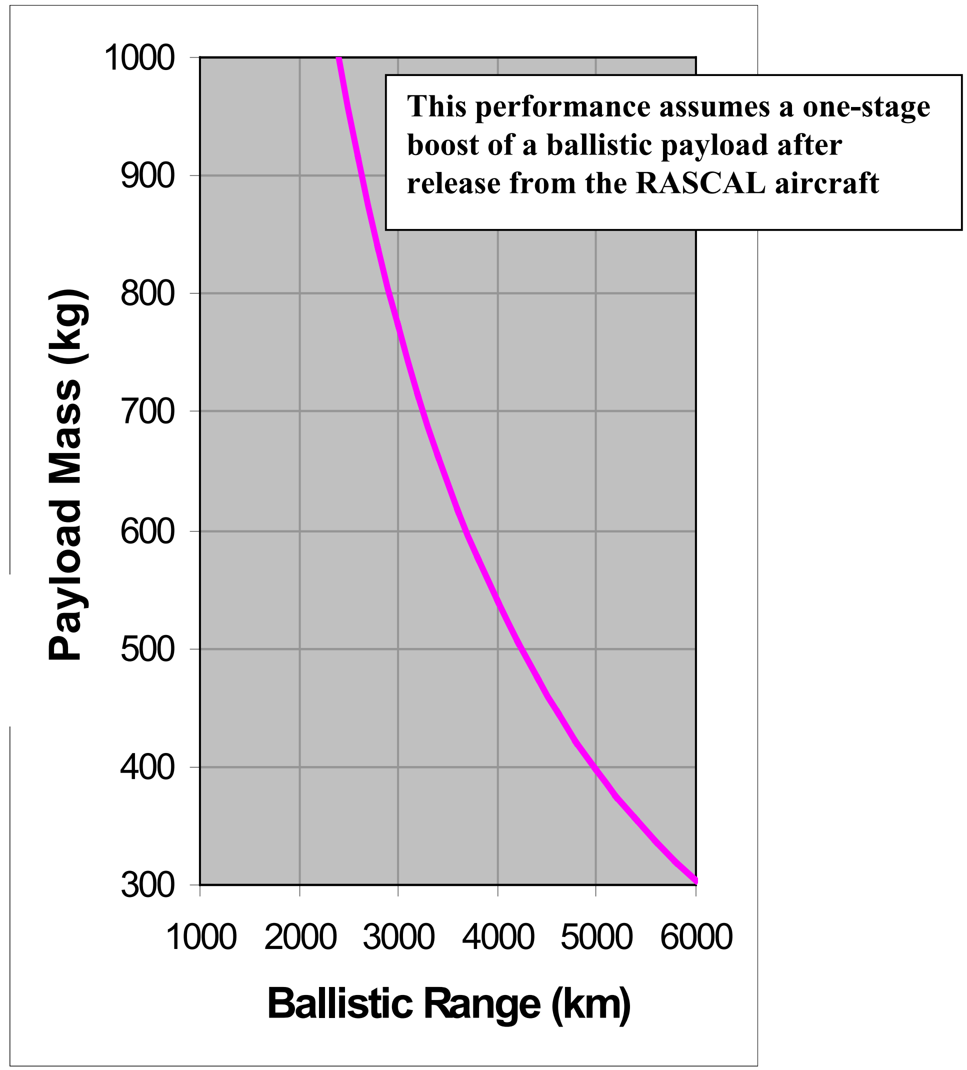
** For "Ballistic" applications assume a minimum capability of 545 kg to desired range

ORBITAL & BALLISTIC PERFORMANCE

Orbital Delivery Potential



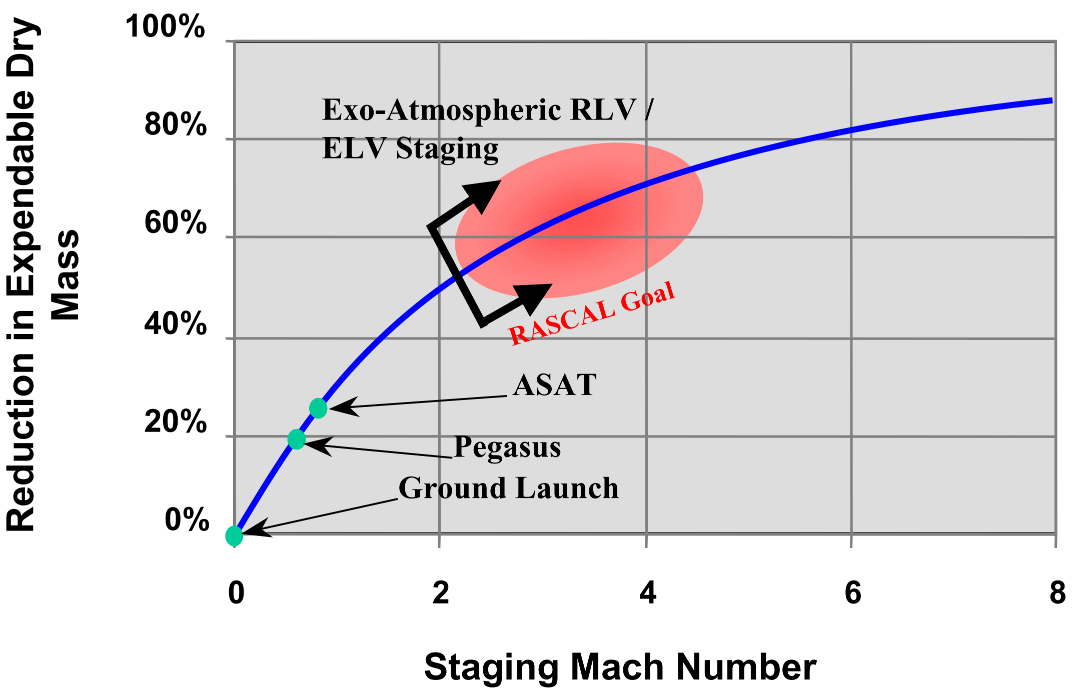
Ballistic Delivery Potential



EXO-ATMOSPHERIC ADVANTAGES

- **Reduces the amount of expendable mass**
  - Reduces the performance & size of the ELV
  - Eliminates the need for a payload fairing
  - reduces recurring cost
- **Reduces the size of the reusable vehicle**
  - Reducing the non-recurring cost of development
  - Reducing the recurring cost of manufacture & maintenance
- **Reduces launch risk**
  - Avoids difficult flight regions
  - Reduces complexity
- **Enables evolution of better reusable vehicles**
  - Vehicle architecture and design not limited by atmosphere
  - As propulsion technology improves, so will the system performance

ZOOM MANEUVER REDUCES THROW AWAY MASS/COST



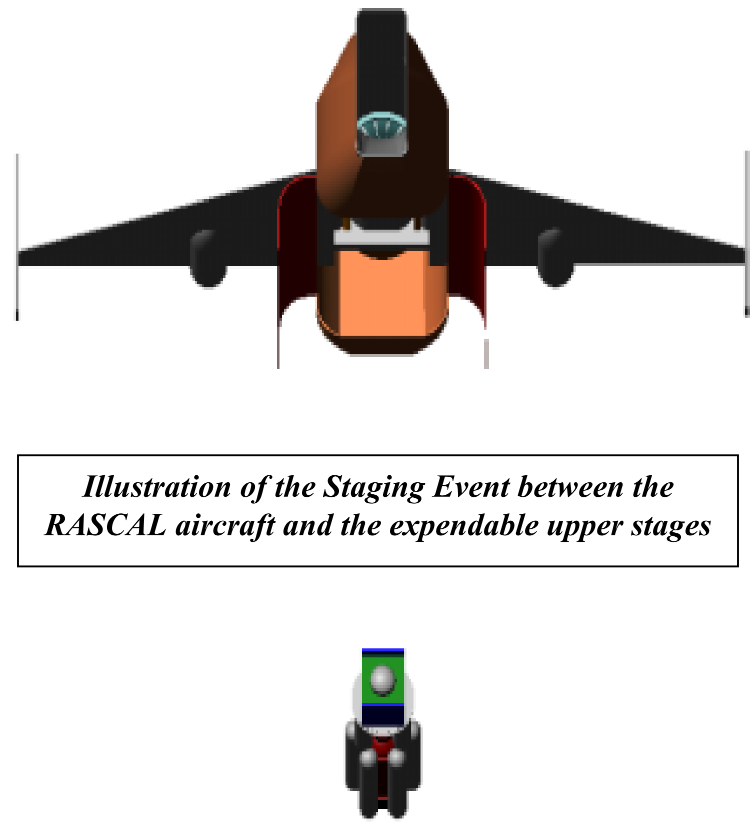
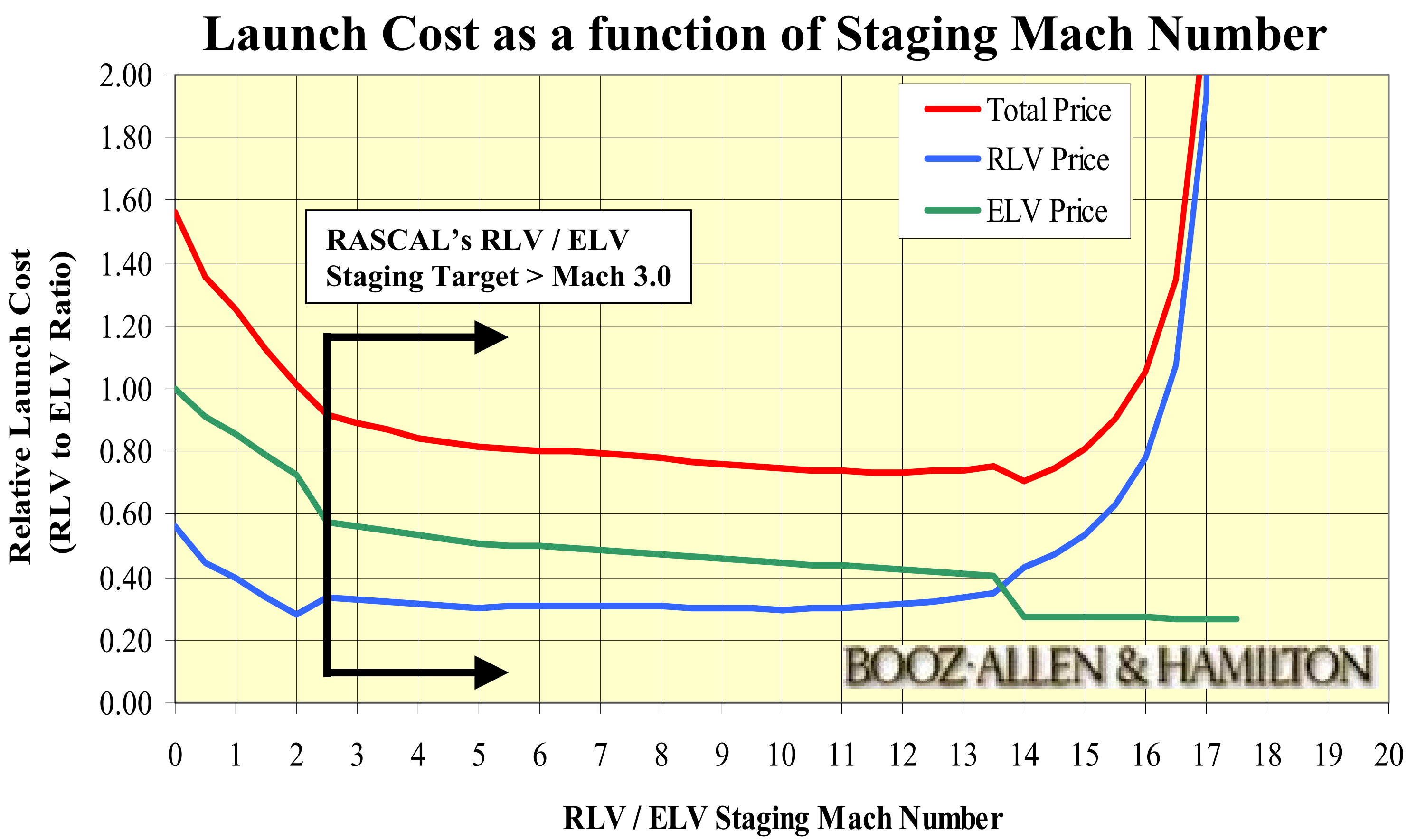


Illustration of the Staging Event between the RASCAL aircraft and the expendable upper stages

- **The Zoom maneuver reduces the amount of expendable mass**
  - **Improves overall system performance**
  - **Reduces recurring vehicle costs**

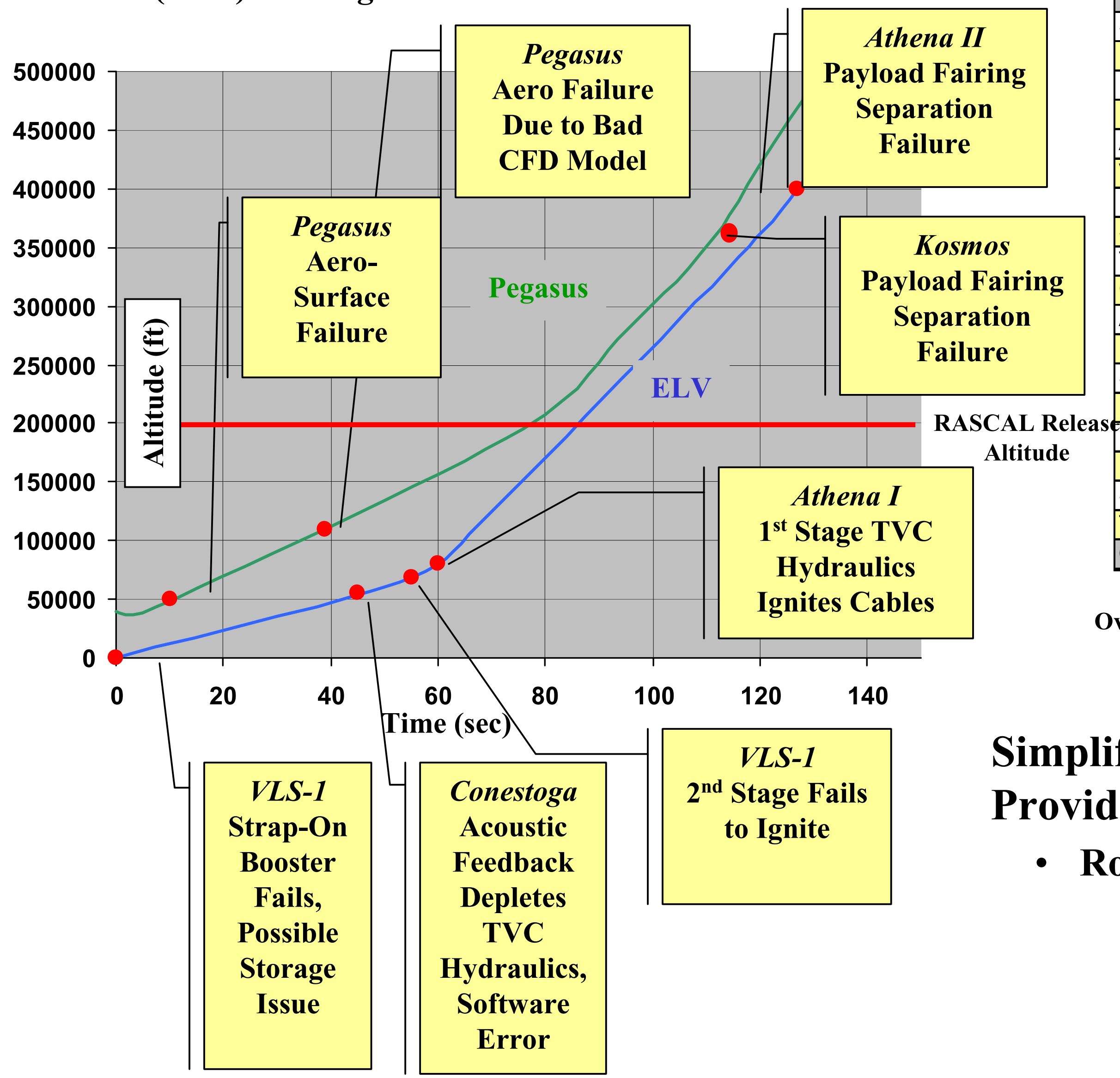
EXO-ATMOSPHERIC STAGING REDUCES COSTS



- **Exo-Atmospheric staging of the ELV rocket provides a cost advantage**
  - **Expendable vehicle is smaller; therefore, recurring cost is lower**
  - **Payload fairing is not required; therefore, not cost is incurred**
  - **Aerodynamic consideration in ELV design are removed; therefore, development cost is reduced**
- **RASCAL target: Staging Mach Number >Mach 3.0**

RASCAL RISK REDUCTION

Launch Trajectories for Expendable Launch Vehicle (ELV) and Pegasus Selected Failures Noted



Small Launch Vehicle Performance Since 1990

Vehicle	Payload (kg)	Cost ($M)	Launches	Failures	Success
Shavit-1	225	18	5	2	60%
Pegasus	332	18	31	6	81%
MU-3S	770	36	4	1	75%
M5	1300	54	3	1	67%
Athena-1	545	18	3	1	67%
VLS-1	250	8	2	2	0%
Minotaur	500	13	2	0	100%
Start (SS-25)	500	11	1	1	0%
Taurus	1070	21	5	0	100%
Conestoga	1100	21	1	1	0%
Athena-2	1575	27	3	1	67%
PSLV	2000	32	5	2	60%
Start-1 (SL-18)	632	10	5	0	100%
Rokot (SS-19)	1200	16	2	0	100%
Kosmos 3M (SL-8)	1100	12	53	3	94%
Dnepr (SS-18)	2000	21	2	0	100%
Shtil (SS-N-23)	430	0.5	1	0	100%
TPD-1	6	NA	1	1	0%
Overall			**128**	**21**	**84%**

50% of Small Launch Vehicle Failures were Endo-Atm
Overall Launch Vehicle (Small-Med-Large) Reliability for Period = 93.4%

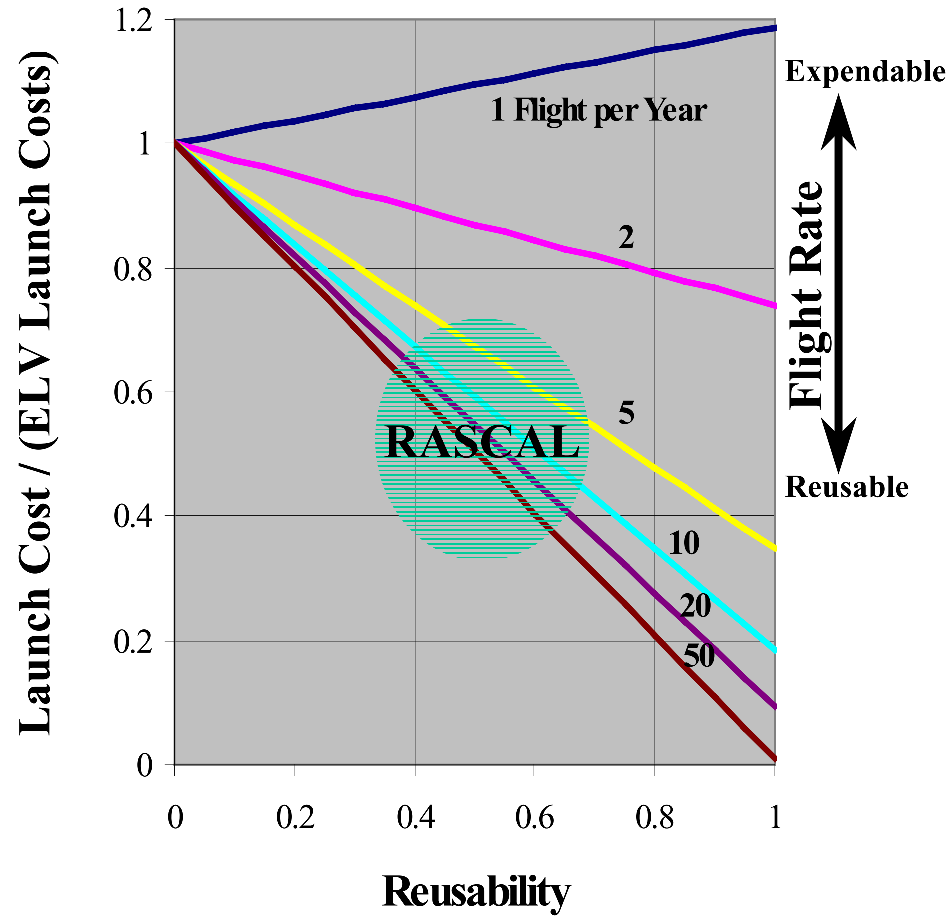
Simplified/Robust Design of RASCAL Provides Risk Reduction

- **Rocket Stages Released Exo-Atmospherically**
  - **No Aero-Surfaces or Modeling Required**
  - **No Payload Fairing Required**
  - **Minimized Need for TVC**

BOOZ·ALLEN & HAMILTON

REUSABILITY AND FLIGHT RATE

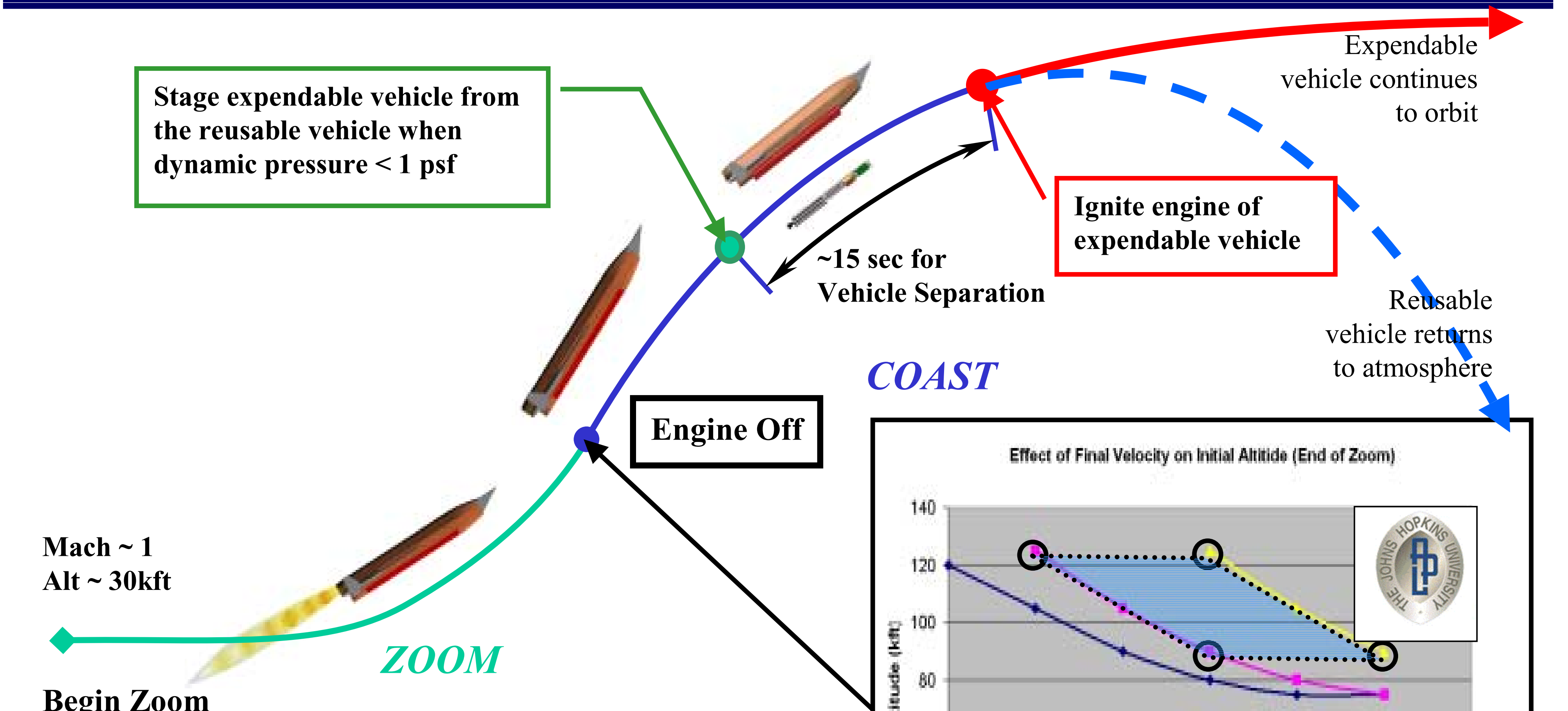
- **Flight rate enables potential cost savings from reusability**
- **Expendable launch vehicles are justified if the flight rate is only a few flights a year**
- **Any level of reusability is justified as the flight rate grows beyond about 5 flights a year**
- **<u>Small payloads</u> can support a high flight rate**
  - **Growth in small payload applications**
  - **No competing small launch vehicles**

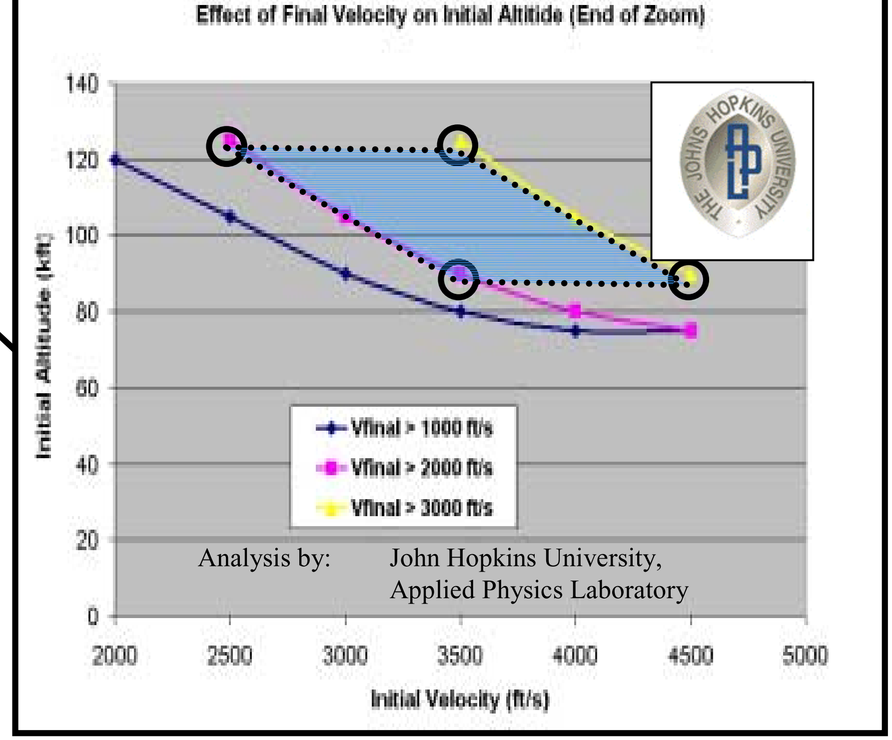


RASCAL's Goal is to achieve 50% reusability

The launch of small payloads should provide enough flight rate to support RASCAL reusability

ZOOM MANEUVER OVERVIEW

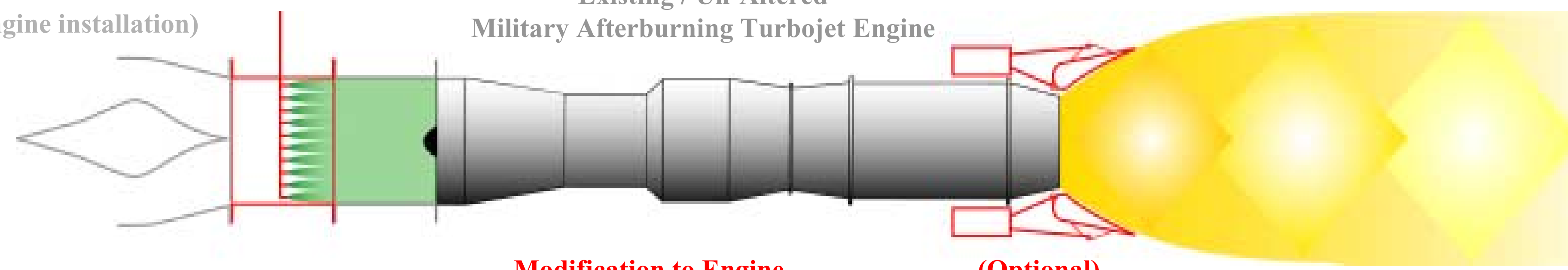




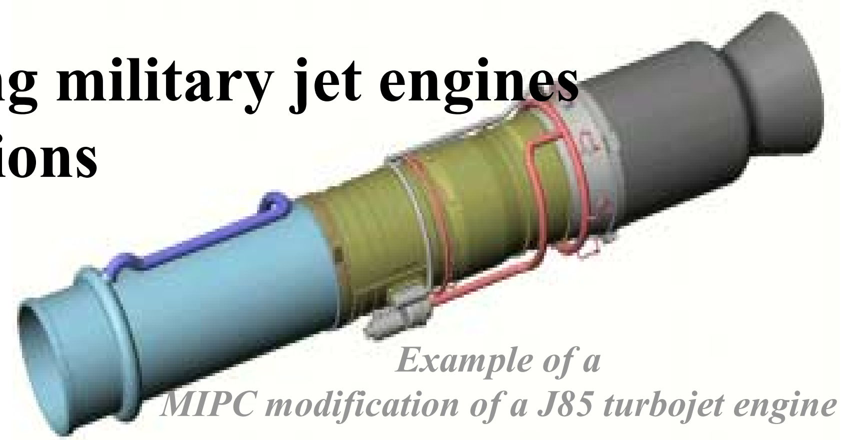
The "Zoom" maneuver requires the RLV engine to take the vehicle beyond Mach 2.5 and 90K ft altitude

- **Coast out of the atmosphere to RLV / ELV staging condition**
- **Coast 15 sec. past the staging event to provide RLV / ELV separation before ELV engine ignition**

MASS INJECTING & PRE-COOLING (MIPC) ENGINES



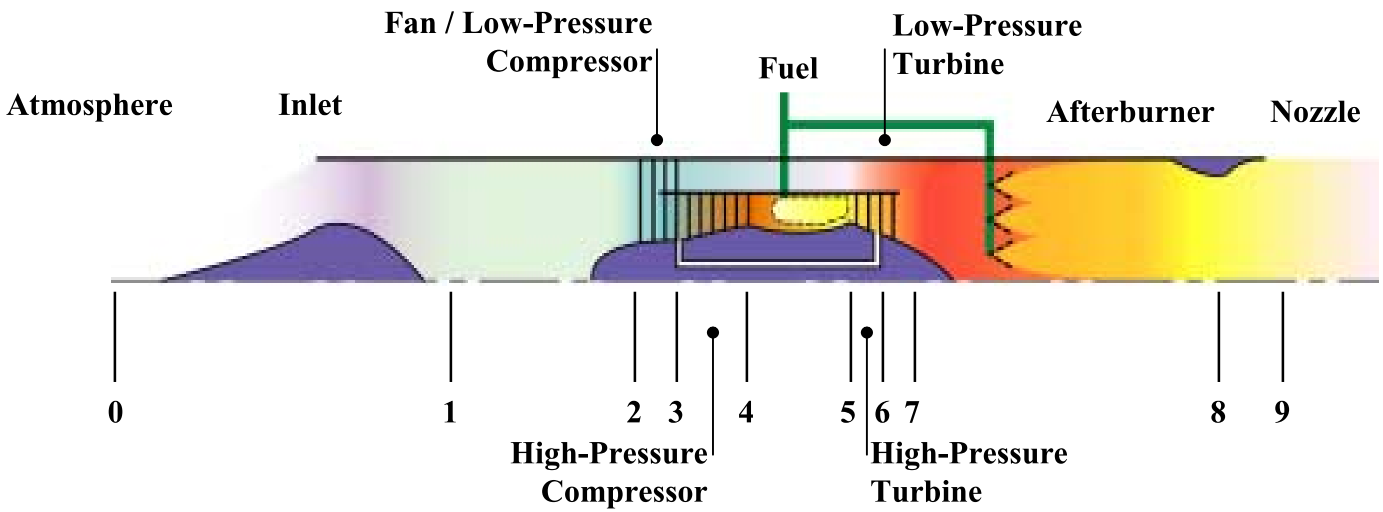
- **MIPC is a method of airframe installation for an existing afterburning turbojet engine**
  - **Enable short term operation to higher flight Mach number**
  - **Enable short term thrust augmentation**
  - **Enable short term operation to higher altitudes**
- **MIPC enables the application of existing military jet engines to space launch / exo-atmospheric missions**



Example of a MIPC modification of a J85 turbojet engine

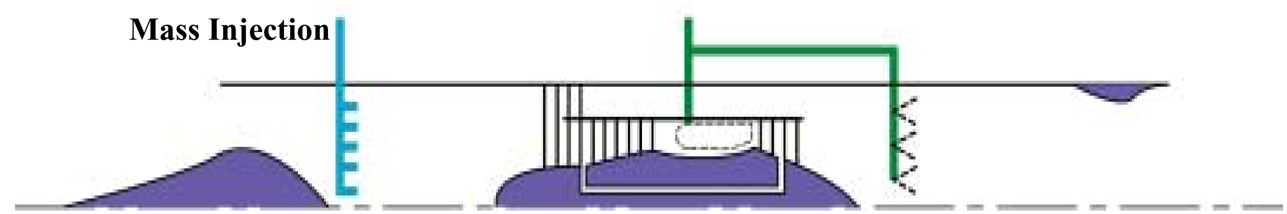
MIPC TURBOJET

Typical Afterburning Turbofan Engine



- **As a turbojet flies to high Mach number, the compressor exit temperature (T3 & T4) rises to the limits of the compressor's material**

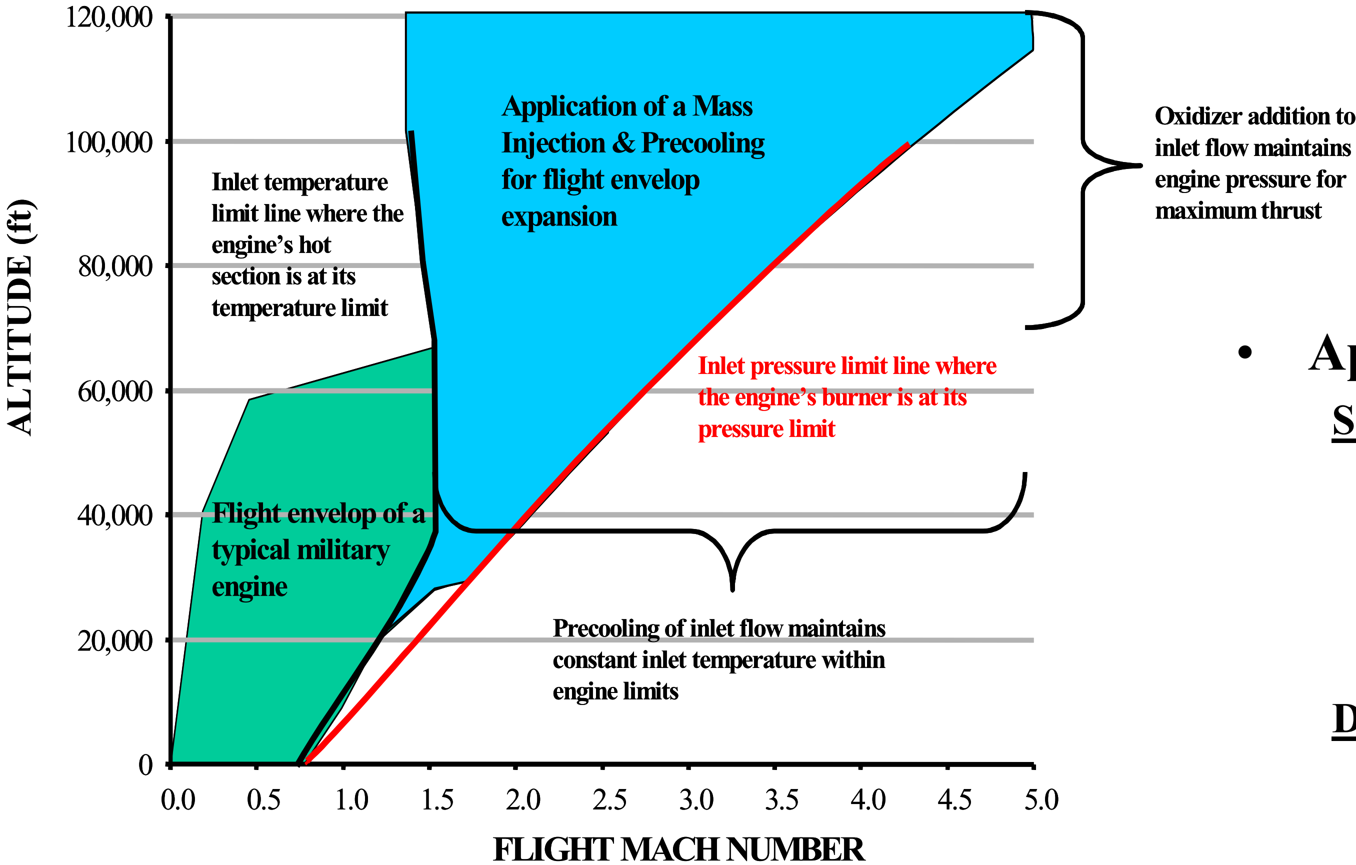
Inlet Modified to provide mass Injection / Precooling



- **A number of fluids can be injected into the inlet to reduce T3 & T4 in order to fly to higher Mach numbers (H_2O, Liquid Air, LOX, N_2O, H2O2, etc.)**
- **The addition of mass to the air flow will also increase engine thrust**
- **If the fluid is an oxidizer, the engine can operate to a higher altitude and have additional thrust**

CHALLENGES / APPROACHES

ADAPTING ENGINES TO MIPC



Pratt & Whitney
A United Technologies Company

- **Challenges**

  Issues: Adapt engine controls to accommodate MIPC while staying with engine normal operating limits

  Goals: Prove MIPC operation to at least Mach 3 and to altitudes greater then 100 kft

- **Approaches**

  Static S.L. Ground Testing:
  - Compressor limits
  - Mechanical / material impacts of MIPC
  - Engine control development

  Direct Connect Ground Testing:
  - Exercise flight envelop
  - Validate designs and modifications
  - Engine control qualification

MIPC RISK REDUCTION

TTO
Tactical Technology Office

SL-1 Test Cell

U.S. AIR FORCE

- Test Section 24’ width x 24’ tall x 71’ long (7.3 m x 7.3 m x 21.6 m)
- Inlet Pressure = Ambient
- Inlet Temperature = Ambient
- Mass flow = 1,000 lbm/sec max
- Thrust = 52.5 Klbf max
- Fuel Flow Rate = 100,000 lbm/hr max
- Data System
  - 64 Channels Temperature
  - 128 Channels Pressure
  - 4 Channels Speed or Flow

Integrity - Service - Excellence

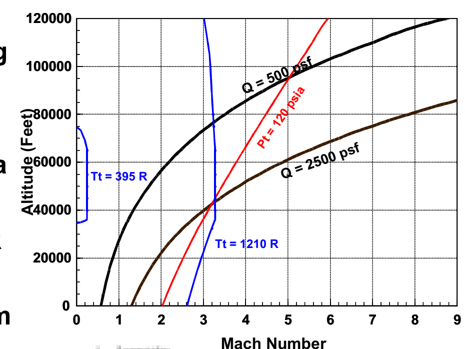
F100 under test at an AEDC Test Cell

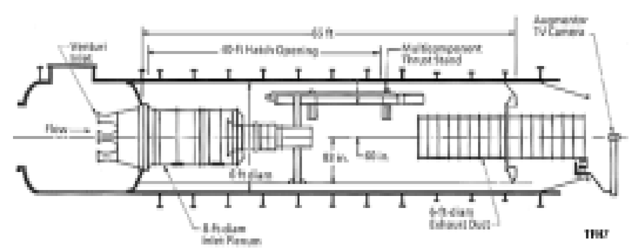
AEDC Facility Survey

J-1 Test Cell

U.S. AIR FORCE

- Test Section 16’ diameter x 65’ long (4.9 m dia x 20 m long)
- Mach No. = 0 to 3.2
- Maximum Total Pressure = 120 psia (827 kPa)
- Total Temperature = 395 to 1210 °R (219 K to 672 K)
- Existing Liquid Air Injection System



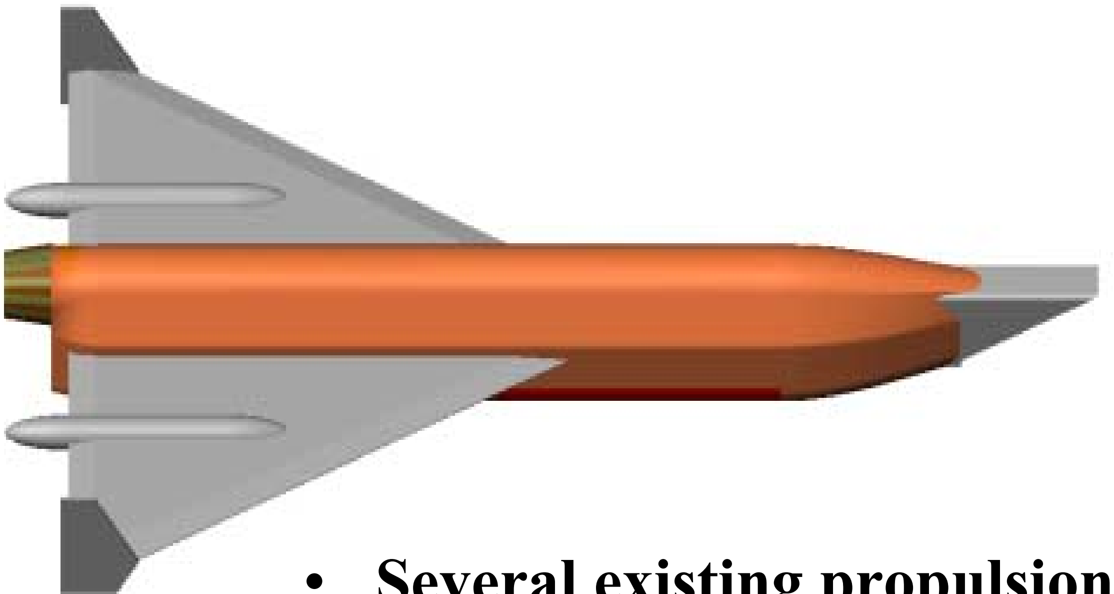


Integrity - Service - Excellence

- All the ground test facilities required to demonstrate and qualify a MIPC engine are available

REUSABLE FIRST STAGE VEHICLE

Notional Vehicle Design



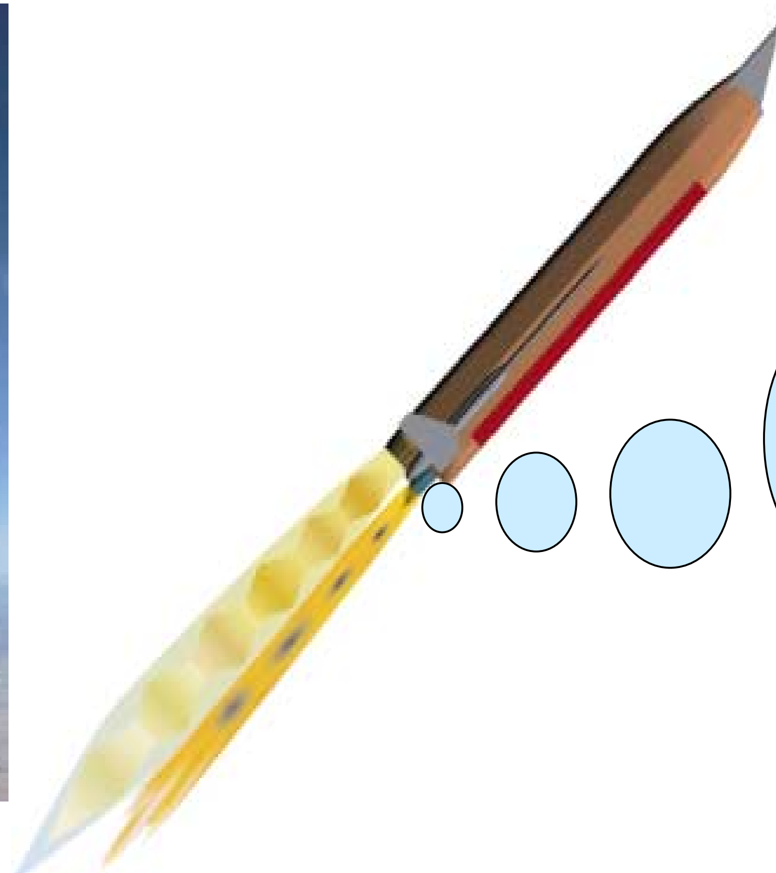
M_{GTOW} = 9375 kg

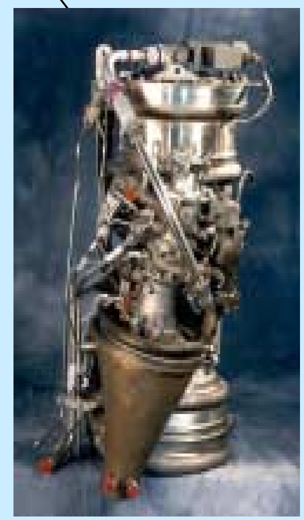
- M_{Fuel} = 2900 kg
- M_{Empty} = 3750 kg
- $M_{Expendable\ Rocket}$ = 2725 kg

Front View

- **Several existing propulsion options are available:**
  - **<u>Mass injected, pre-cooled, (MIPC) turbojet engines</u>**
  - **<u>Reusable rocket engines</u>**
- **Developed from existing engine designs and airframe technology**
  - **Modified existing aircraft? (Possible)**
  - **New vehicle? (Fewer compromises, Better performance)**
- **Designed for loiter and <u>zoom</u>**

ROCKET BOOSTED ZOOM



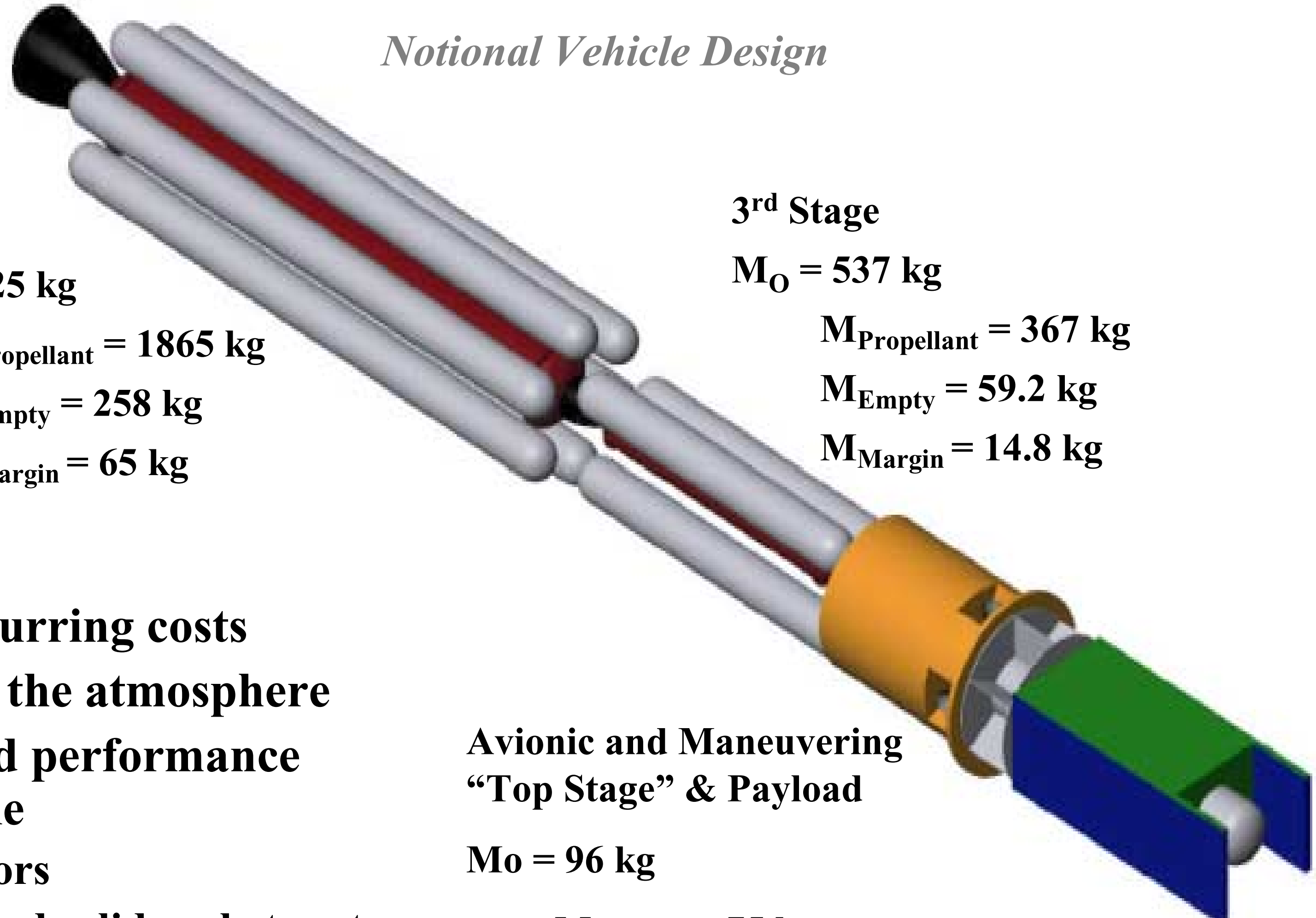


Boeing / Rocketdyne AR2-3
H2O2 / JP Reusable Aircraft
Rocket Engine

- The Rocketdyne AR2-3 engine boosted the NF-104 aerospace trainer, operationally, for 7 years
- This engine is being used by the current NASA X-37 spaceplane

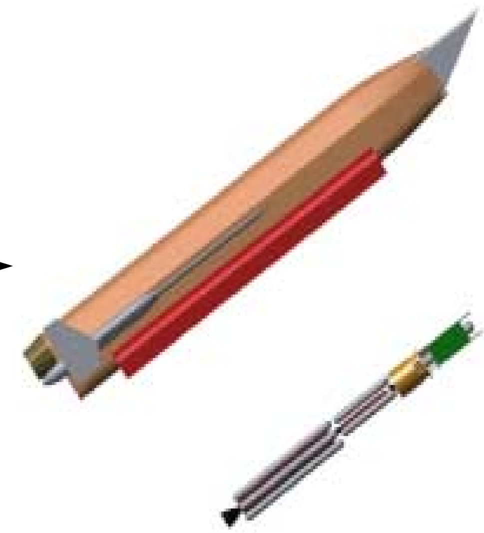
EXPENDABLE VEHICLE

Notional Vehicle Design



- **Designed for low recurring costs**
- **Only operates out of the atmosphere**
- **Several low cost/good performance technologies available**
  - **Hybrid rocket motors**
  - **Tactical missile based solid rocket motors**
  - **Pressure-fed liquid propulsion**
  - **Miniature pump-fed liquid propulsion**

TOP STAGE



- **Top Stage provides:**
  - **Vehicle's guidance control through "Head End Steering"**
  - **Carries all of the vehicle's avionics**
  - **Provide orbit insertion maneuvering delta-V**

- **A Top stage architecture allow many propulsion technologies to be used for the ELV by simplifying integration**